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Soil Water Dynamics Under Conventional and Alternative Cropping Systems at Two Sites in Central Alberta.

by

Lenz-Kevin Jules Lothar Ludwig Haderlein ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science.

Department of Soil Science
Edmonton, Alberta
Spring, 1995

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled SOIL WATER DYNAMICS UNDER CONVENTIONAL AND ALTERNATIVE CROPPING SYSTEMS AT TWO SITES IN CENTRAL ALBERTA. submitted by Lenz-Kevin Jules Lothar Ludwig Haderlein in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE

R César Izaurralde
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Date: April 7/95

For my Family:

Angela, Konrad, Marianne, Jules and Lucie

Abstract

The water use patterns of a continuous barley (*Hordeum vulgare* L.) cropping system and a four year rotation cropping system which included barley, faba bean (*Vicia faba* L.), barley and barley-field pea (*Pisum sativum* L.) intercrop were studied from 1989 to 1992 at two sites in central Alberta: Ellerslie (Black Chernozem) and Breton (Gray Luvisol). Parameters used to compare the two cropping systems were: (1) amount of soil water present during the growing season, (2) seasonal evapotranspiration (ET), and (3) crop water-use efficiency (WUE). The effects of tillage and weed control practices on soil water within the rotation system were also studied. Seasonal amounts of soil water were similar between cropping systems at Ellerslie, but differed at Breton. At both sites, seasonal ET values of the cropping systems were similar. At Ellerslie WUE of continuous barley was greater than that of the rotation. At Ellerslie, tillage affected water holding properties of the soil and weed management affected the number of weeds present within the rotation cropping system. The Breton site was better suited to cropping systems which included annual legumes than Ellerslie over four years because of lower fertility and greater seasonal precipitation.

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Chapter 1.
Introduction

1.1 Background

The effects of agricultural management practices on soil quality are of concern to producers, policy makers and the public. The introduction of mechanized agriculture to central Alberta in the early 1900s replaced the natural grassland and boreal forest vegetation with crop plants, exposing soils to potential changes in nutrient cycling and physical properties. While the effects of these changes are still being assessed, there is awareness that current and past agricultural management practices in this region have resulted in soil loss, nutrient loss, and a decrease in soil productivity (Standing Senate Committee on Agriculture, Fisheries and Forestry, 1984). In an effort to slow the rate of soil degradation under present agricultural management practices, research has focused on creating new management systems which are "sustainable".

Sustainable agriculture is a term which describes a philosophy of agricultural management. A definition of this term by Agriculture Canada states that:

> "Sustainable agricultural systems are those that are economically viable, and meet society's needs for safe and nutritious food while conserving and enhancing our natural resources and the quality of the environment for future generations." (Campbell, 1991).

Cropping systems which have been proposed to meet this definition use strategies such as reduced soil disturbance and increased crop diversity to reduce soil erosion, improve nutrient cycling and optimize the level of inputs. Studies of comparative resource use in alternative and conventional systems may determine if the environmental quality in agroecosystems can be maintained or improved by changing management strategies.

Jensen (1988) found that 81% of cropped land in Alberta was farmed using fallow, continuous cropping, or short term cereal and oilseed-based crop rotations. These systems are highly productive, but are not considered sustainable because of their reliance on non-renewable resources such as fossil fuels and mined minerals (Pimentel and Heichel, 1991). Alternative cropping systems which have been proposed for central Alberta include short-term rotations including annual legumes, reduced tillage and non-chemical methods of weed control (Izaurralde *et al.* 1993). The goals of such systems are to maintain soil quality and reduce reliance on external inputs, while maintaining the producer's income. If alternative cropping systems can achieve these goals is still unknown.

The relative performance of conventional and alternative cropping systems in central Alberta has been studied by Izaurralde *et al.* (1993). They found that annual legume species could be successfully grown in this region, and suggested that these crops would benefit soil productivity. The use of water resources in these cropping systems has also been studied (Izaurralde *et al.* 1994). The authors reported that alternative crops such as faba bean (*Vicia faba* L.) and barley (*Hordeum vulgare* L.)-field pea (*Pisum sativum* L.) intercrops had different levels of water use and water use efficiency than conventional crops such as barley grown alone. They also suggested the need for research on the use of water resources in rotational cropping systems which included these crops.

Water is the one of the most limiting factors in crop production, yet only a few studies have discussed the combined effects of cropping, soil and management variables on water use (Izaurralde *et al.* 1994; Radke *et al.* 1988; Abdul-Jabbar *et al.* 1983). Such studies take an approach of analyzing crop and management factors together to determine the relative effectiveness of each cropping system at using the available water resources. However, many studies have provided information about the characteristics of water use for individual crops and management techniques. Such research can be used as a basis for an integrated study into the effects of cropping systems on soil water, evapotranspiration and water-use efficiency.

1.2 Study Objectives

The main objective of this study is to compare soil water dynamics between conventional and alternative cropping systems in central Alberta. This will be accomplished by analyzing data collected from cropping systems studies at two sites representing contrasting soils in the region. Information is presented in three chapters, each with individual objectives:

The objective of Chapter 2 is to determine the effects of cropping systems and treatments within each cropping systems at two sites on the amount of soil water, soil water recharge, seasonal evapotranspiration, and water use efficiency over a four-year period.

Chapter 3 discusses the effects of tillage systems within an alternative cropping system at two sites on soil texture, bulk density, water holding properties and hydraulic conductivity.

Chapter 4 discusses the effects that contrasting weed control methods within an alternative cropping system have on weed populations and soil water dynamics.

Chapter 5 provides a synthesis of the results reported in Chapters 2 through 4 and presents conclusions drawn from the study.

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Standing Senate Committee on Agriculture, Fisheries and Forestry. 1984. *Soil at risk: Canada's eroding future.* 129pp.

Chapter 2.

Soil water dynamics under conventional and alternative cropping systems at two sites in central Alberta.

2.1 Introduction

Cropping systems which have been proposed to meet the definition of sustainable agriculture use strategies such as reduced soil disturbance and increased crop diversity to conserve soil and improve resource-use efficiency. Comparing alternative cropping systems to conventional cropping systems may determine if the environmental quality in agroecosystems can be maintained or improved by changing management strategies. One of the main resources required in cropping systems is water. Its efficient use is crucial in creating sustainable cropping systems. Therefore, in order to determine the viability of an alternative cropping system, its water use patterns must be determined.

Studies of crop-water relationships often include the terms evapotranspiration (ET), transpiration efficiency (TE), water requirement (WR) and water use efficiency (WUE). Definitions of these terms are outlined by Viets (1962). ET is the volume of water used by plant growth through transpiration, combined with evaporation from soil and intercepted precipitation on an area in any specified time, and is expressed in mm per area. TE and WR are related terms which express the relationship between the amount of water transpired by a plant over time and the amount of dry matter produced by the plant in that time. TE is expressed in kg mm^{-1} while WR, its inverse, is in mm kg^{-1}. WUE relates the combined transpiration and evaporation components of the water balance (ET) with dry matter (DM) production, while TE includes only the transpiration component.

$$\mathrm{WUE} = \frac{\mathrm{DM}\,(\mathrm{kg})}{\mathrm{ET}(\mathrm{mm})} \tag{2.1}$$

Early work in crop-water relationships focused on determining water requirements of field crops under different soil and climatic conditions. Briggs and Shantz (1914), used data compiled in container experiments across the United States to conclude that water requirement varied greatly between crops. Legume crops were found to have the greatest water requirement, while millet (*Pennisetum americanum* L.), corn (*Zea mays* L.) and sorghum (*Sorghum bicolor* L.) had the lowest WR. Small grain crops such as wheat (*Triticum aestivum* L.), had intermediate water requirements. As well, severe nutrient deficiencies in the soil were found to increase the water requirement of all crops. In a review of water use literature, Tanner and Sinclair (1983) found that transpiration efficiencies for given crops were relatively constant across a range of climates and fertility levels and that these variables could be accounted for by using correction factors. Arkley (1963) used growing season relative humidity as a climatic correction factor, while deWit (1958) used pan evaporation to correct TE. Transpiration efficiency and WR parameters considered in these studies require evaporation and transpiration to be considered separately. Since this separation is not always possible, the use of the ET derived parameter of WUE may be more practical under large-scale field conditions.

For large areas, ET can be estimated using the "water balance" approach. Thornthwaite (1948) created climatic classifications for the United States by using the difference between the monthly precipitation and potential evapotranspiration of each region as an index. He proposed that this index was a measure of the surplus or deficit of soil water, and that an excess of soil water would lead to surface runoff or subsurface drainage. This hydrologic balance can be expressed in the form:

$$P - R = ET + D \pm \Delta W \qquad (2.2)$$

P represents added precipitation and R is surface runoff. D is the subsurface drainage component and ΔW is the change is soil water storage over the time period. ET can be calculated from this equation if values or estimates of P,R,D and ΔW are available. WUE of a crop can then be calculated using this value of ET and the above ground dry matter yield.

Many studies have used the water balance approach as a tool to describe the interactions between individual types of management, soil, or crop on soil water dynamics. A number of these studies have focused on the interactions between management and water dynamics in field crops. The relationship between water availability and water use of annual cereals has been examined in the U.K. by Day *et al.* (1978). Twelve barley (*Hordeum vulgare* L.) treatments were protected from rainfall by mobile shelters in order to create a range of soil water deficits and irrigation timings. They found that there was a linear relationship between grain yield and water use for all treatments and that the timing of irrigation did not significantly affect the grain yield. A continuation of this experiment by Day *et al.* (1987), compared the same treatments in two contrasting years: 1976 and 1979. They concluded that the grain yield-water use relationship differed in slope between the two years, but relative differences between treatments remained the same. Kallsen *et al.* (1982), working in New Mexico, concluded that the timing of water application affected WUE, because of the effects of increased surface evaporation. However, they also found that if E and T could be separated, the linear function of T vs. grain yield would be the same at a given location with any set of water deficit and irrigation variables.

The management of soil nutrients has been found to affect water use in field crops. A thorough review of early data was conducted by Viets (1962). He found that in studies where fertilizer had increased yield, ET had either increased according to the fertilizer application or remained the same as treatments receiving no fertilizer. He concluded that in either case the application of fertilizer increased the WUE of the crop by reducing surface evaporation through changes in plant cover and color. In a continuation of their previous work, Kallsen *et al.* (1984) concluded that the addition of N fertilizer did not affect the TE of spring barley in New Mexico, but that WUE was affected, due to the increase in surface evaporation in treatments with low N fertility. Campbell *et al.* (1977), working with lysimeters in Saskatchewan, found that under semi-arid conditions, N fertilized wheat treatments had a greater WUE than unfertilized treatments, but that beyond a certain rate of N application (61.5 kg ha^{-1}) there was no increase in WUE. They proposed that N application beyond this limit resulted in rapid root and shoot development early in the growing season, when soil water was adequate. This increased production resulted in a greater ET, and a greater rate of soil water depletion, leaving less water available for later growth stages of the crop.

The effect of crop type on soil water use has also been studied by several researchers. Hattendorf *et al.* (1988) compared the evapotranspiration rates of six crops at three sites in Kansas, and concluded that sunflower (*Helianthus annus* L.) had a greater daily water use than pinto bean (*Phaseolus vulgaris* L.), soybean (*Glycine max* L.), wheat, corn, sorghum and pearl millet. Badaruddin and Meyer (1989) found no difference between the WUE of grain legumes [pinto bean, soybean, lentil (*Lens culinaris* L.) and faba bean (*Vicia faba* L.)] and wheat in North Dakota.

They concluded that soil water content in a rotation including annual legumes would not be significantly different from continuous cereal or fallow cropping systems. Water use and protein production of faba bean were studied by Krogman et. al. (1980). They found that seasonal ET in irrigated faba bean was at least 16% higher than that of irrigated cereals, and that this higher water use translated into a correspondingly higher dry matter production. As part of a crop-soil-tillage study in central Alberta, Izaurralde *et al.* (1994) reported comparisons in WUE between barley, barley- field pea intercrop, faba bean and creeping red fescue (*Festuca rubra).* WUE for barley- field pea intercrop was greater than that of the other crops. This difference was attributed to a denser canopy in the mixed cropping system, which was thought to reduce surface evaporation. Growing season ET of the barley-field pea intercrop was similar to that of barley alone (306 mm vs. 309 mm) while significantly higher ET values were recorded for faba bean (407 mm) and creeping red fescue (410 mm).

Management practices such as tillage and residue management and their effect on soil water dynamics have also been studied. Comparisons of soil water under reduced tillage or no till (NT) systems with conventional tillage (CT) systems have found higher seasonal water contents under NT (Blevins *et al.* 1971; Johnson, *et al.* 1984; Zhai *et al.* 1990; Arshad and Dobb 1991; Singh 1991). Larger amounts of soil water under NT have been attributed to differences in soil physical properties between CT and NT. These differences may lead to reduced evaporation, increased infiltration and greater hydraulic conductivity under NT. Greater soil water storage under NT does not always correspond to a difference in crop water use. Deibert *et al.* (1986) reported that water storage in a NT continuous wheat cropping system in North Dakota was higher than that of a CT system, but that there was no significant increase in yield or WUE related to the water surplus. They concluded that spring wheat under NT was less able to extract water due to a shallow rooting depth when compared to the same crop under CT, and thus did not take advantage of the increased water storage in the NT treatment. In contrast, Lafond *et al.* (1992), found that the increased soil water in NT and minimum tillage systems compared to CT corresponded to an increase in yield for field pea (*Pisum sativum* L.), flax (*Linum usitatissimum* L.) and spring wheat in Saskatchewan. In central Alberta, Izaurralde *et al.* (1994) reported no significant differences in either ET or WUE between crops grown under NT and CT.

In soils where root restriction and poor drainage are known to be problems, alternative management strategies such as deep tillage may enhance crop water uptake (Eck and Taylor 1969; Bradford and Blanchar 1977; Rowse and Stone1981). In New Zealand, Rengasamy and Reid (1993) reported that deep tillage altered the root distribution of faba bean resulting in changes in soil water distribution and an increase in WUE when compared to CT treatments. Yield increases for faba bean with deep tillage treatments have also been reported on a Luvisolic soil in central Alberta by Izaurralde *et al.* (1993).

There is relatively little research which incorporates the interactive effects of crop, soil and management on soil water dynamics. Abdul-Jabbar *et al.* (1983) studied water use of three crops [alfalfa (*Medicago sativa* L.), corn and barley] at three sites in New Mexico to determine the relationship between ET and soil water content for each crop in that area. Curves of relative ET to available water were plotted and compared for site, irrigation and crop variables. They found that this relationship differed for each of the crops, and that the physical properties of the soils at each site had an effect on the shape of the curves. In Australia, Beech and Leach (1989) studied the effects of plant density on the water use of safflower (*Carthamus tinctorius),* chickpea (*Cicer arietinum*) and wheat. Crop type and seeding density both had significant effects on the extraction of water, particularly at depths below 0.3 m. The authors concluded that safflower had the lowest WUE at all plant densities, while wheat had the highest.

A comparison of the soil water dynamics of conventional and alternative cropping systems in central Alberta has been published by Izaurralde *et al.* (1994). This study emphasized individual cropping and tillage treatments and their interactive effects on soil water dynamics, ET and WUE. Although soil water distribution was studied at two sites with contrasting soil types, the hydrologic balance of the Breton site was considered to be affected by factors such as surface runoff and subsurface flow, and ET and WUE calculations were not made at that site.

The work presented here will attempt to expand on the findings of Izaurralde *et al.* (1994) in several ways. In 1989, continuous annual cropping was replaced by a four-year rotation cropping system in several treatments. This rotation system which includes annual legumes for N fixation and weed and disease control reflects the desire to create an alternative to cropping systems which rely heavily on outside inputs to maintain nutrient cycling and weed control. The objectives of this study are: Firstly, to determine the effect of cropping systems on soil water dynamics. More specifically, to establish whether the rotation annual system, annual continuous cropping system and the continuous forage system differ in spatial or temporal distribution of soil water both over a four-year period and within specific discharge and recharge periods at two sites. Secondly, to compare the performance of two annual cropping systems at two sites with respect to ET and WUE. This will be accomplished by including information about the ET and WUE of specific cropping treatments to establish the overall comparison. Thirdly to compare the effects of tillage-management treatments on soil water, ET and WUE within each cropping system and overall at each site. And finally, to discuss, in general terms, any overall differences in the above comparisons between the two sites.

2.2 Materials and Methods

2.2.1 Study Sites: Soil and Climate.

The study was conducted over four years at two sites in central Alberta. The sites chosen for the study represent two contrasting soil types common to agricultural lands in this area. The first site was the University of Alberta Ellerslie Research Station located in Edmonton at 53° 25' N latitude and 113° 33' W longitude at an elevation of 686 m. The soils at this site have been formed on the fine-textured glaciofluvial and glaciolacustrine deposits of glacial Lake Edmonton under grassland and forest-grassland transition vegetation (Kathol and McPherson 1975; Crown and Greenlee 1978). Orthic Black Chernozems of the Malmo silty clay loam series are dominant at this site. These soils are characterized by a black surface (Ap) horizon 0.3 m thick, a thin eluvial horizon, and a fine textured illuvial horizon (Table 2.1). Carbonates are often present at depths near 1 m (Bowser *et al.* 1962). The slope at this site is less than 2%, and the soils here are considered moderately well drained.

The climate classification at Ellerslie is considered Cryoboreal-subhumid (Government of Alberta and University of Alberta 1969) and is characterized by a wide range between mean winter and mean summer temperatures. Mean annual precipitation is 452 mm, of which approximately 60% falls as rain during the growing season from May to August (Fig. 2.1). Selected climatic means for the Ellerslie site are given in Table 2.2.

The second site was located approximately 110 km south-west of Edmonton on the University of Alberta Breton Plots, near the hamlet of Breton (53° 07' N latitude, 114° 28' W longitude, at 850 m elevation). Soils at this site have formed on moderately fine-textured glacial till material. These soils are mapped as the Breton loam series, and are classified as Orthic Gray Luvisols and Gleyed Gray Luvisols, having formed under boreal forest vegetation (Lindsay *et al.* 1968). Properties of a soil in a well-drained position at the Breton site are given in Table 2.1. Internal drainage at this site ranges from well-drained to imperfectly drained. Slopes range from 1% to 6% and the runoff potential of this soil is considered moderate (Crown and Greenlee 1978).

Climate classification of the Breton site is Cryoboreal-subhumid (Government of Alberta and University of Alberta 1969), similar to that of the Ellerslie site. The Breton site has, on average, a shorter growing season, fewer growing degree days above 5° C and greater amounts of annual precipitation than the Ellerslie site (Table 2.2). Mean annual precipitation from the Breton townsite meteorological station and temperature distributions for Winfield (approximately 15 km from the study site) are presented in Fig. 2.2.

2.2.2 Field Study Description

The study was conducted from 1989 and 1992. The plots, known as the NSERC (Natural Sciences and Engineering Research Council) plots were established in 1986 to compare the performance of cropping systems using faba bean, barley, barley-field pea intercrop and creeping red fescue under several management regimes (Izaurralde *et al.* 1990, 1992, 1993, 1994). In 1989, short-term crop rotations were initiated under two tillage systems at both sites and individual treatments were grouped into three cropping systems:

1. Rotation annual crops,
2. Continuous annual crops, and
3. Continuous Forage (creeping red fescue).

The crop rotation initiated in 1989 at both sites followed the sequence (1) barley, (2) barley-field pea intercrop, (3) barley (4) faba bean. The rotations were established such that each phase of the rotation was present every year with two replicates. Continuously cropped barley treatments were also replicated twice for each management system. There were eight replicates for the creeping red fescue treatment at each site. Plot sizes were 24.7 x 9.3 m at Ellerslie and 12 x 6.8 m at Breton. The management systems for annual crops at Ellerslie consisted of two tillage systems: no tillage (NT) and conventional tillage (CT). Under NT management, there was no mechanical soil disturbance except for the seeding operation, while the CT system consisted of two or three tillage operations per year using chisel ploughs, field cultivators, disks or harrows (section 2.2.3). At Breton, the two tillage practices were CT, and deep tillage (DT). The DT system consisted of an annual chisel operation to a depth of 0.3 m followed by conventional tillage operations. The chisel operation was intended to produce partial mixture of the Bt and Ap soil materials, thereby increasing the clay content of the Ap horizon.

Rotation crops at Breton and under CT at Ellerslie were grown under a low input (LI) management system. In this system N was supplied by the fixation of atmospheric N by the legume species, P was provided by an annual application of P as treble superphosphate fertilizer (9 kg ha^{-1}) at the time of seeding, and weed control was provided by tillage and crop competition. No tillage rotation treatments at Ellerslie used a modified form of the LI system, where N and P were supplied in the same manner as in the LI system but weeds were controlled by the application of herbicides. Continuous barley cropping systems at both sites were split into two treatments, one in which urea N (50 kg ha^{-1}) was banded into the soil each year at the time of seeding to supplement N derived from soil, and one where N was derived only from the soil. Phosphorus in the form of treble superphosphate fertilizer (9 kg ha^{-1} P) was added to these treatments at seeding time, and weed control was provided by application of herbicides. The continuous creeping red fescue treatments were seeded in 1986. N and P were supplied yearly through additions of fertilizers, and weeds were controlled by annual applications of herbicide.

2.2.3 Crop and Soil Management

Annual crops were seeded in May of each year at both sites (Table 2.3). Three six-row barley cultivars were used over the study period. Heartland was seeded in 1989 and replaced in 1990 with Duke, a cultivar with improved lodging resistance. In 1992 the cultivar Leduc was used. Barley monocrops were seeded at the recommended rate of 90 kg ha^{-1} in all years. Intercrops were seeded at 60 kg ha^{-1} of barley and 90 kg ha^{-1} of field pea. The field pea cultivars used were Trapper in 1989 and the semi-leafless Radley from 1990 to 1992. The faba bean cultivar Outlook was seeded in 1989 and replaced by Herz-Freya from 1990 onward. The seeding rate for faba bean was 210 kg ha^{-1}.

In mid-June, approximately three weeks after emergence, continuous cropped and NT barley at Ellerslie received applications of herbicides. In 1989 and 1990 a mixture of Cyanazine + MCPA {[2-[[4-chloro-6-(ethylamino)-s-triazin-2yl]amino]-2-methylpropionitrile] and [2-methyl-4 chlorophenoxyacetic acid]} was applied at product rate 2.25 L ha^{-1}. In 1991, a mixture of Diclofop Methyl + Bromoxonil {methy 2-[4-(2,4-dichlorophenoxy) phenoxy] propionate and 3,5-dibromo-4-hydroxybenzonitrile} at product rate 3.5 L ha^{-1} was applied to these treatments. The herbicide used in 1992 was Thiefensulfuron methyl {methyl 3-[[[[[4-methoxy-6-methyl-1,3,5-triazin-2yl]amino]carbonyl]amino]sulfonyl]-2-thiophenecarboxylate} at product rate 20 g ha^{-1}. NT faba bean plots received post emergent applications of Bentazon [3-(1-methyl-ethyl)-(1H)-2,1,3-benzothiadiazin-4(3H)-one 2, 2-dioxide] at a product rate of 1.5 L ha^{-1}. NT barley-field pea plots received post emergent applications of MCPA + MCPB a 15:1 mixture of the sodium salts of MCPB [4-(2-methyl-4 chlorophenoxy) butyric acid] and MCPA. at a product rate of 1.5 L ha^{-1}. At Breton, continuous cropping treatments received pre- and post-emergent herbicides, similar to those at Ellerslie. Fescue treatments at both sites were treated with 2,4-D (2,4-dichlorophenoxy acetic acid) or MCPA (at product rates of 2.0 L ha^{-1}) in early June.

Fescue treatments were harvested in early July each year and yields determined by collecting the plant material from four 1 m^2 quadrats on each plot, drying the samples for 72 h at 60°C and then weighing them. The remaining crop was removed from each plot. Annual crops were harvested between mid-August and mid-September (Table 2.3). Six 1 m^2 samples were taken from each plot, dried for 72 h at 60°C and threshed using a stationary thresher to determine seed and dry matter yield. Plants remaining on barley and intercrop plots were swathed and threshed using full-sized field machinery. Crop residues were returned to these plots after threshing. In faba bean treatments, the remaining plants were removed from the plot as forage.

Post harvest management at Ellerslie consisted of cultivation of CT plots with a chisel plough to a depth of 0.1 m to incorporate surface residues. NT plots were treated with an application of Glyphosate [N-(phosponomethyl) glycine] at a product rate of 2.5 L ha^{-1} to control perennial weeds. At Breton, all plots received light cultivation with a tandem disk to a depth of 0.1 m after harvest. Prior to freezing of the soil in October, DT treatments were cultivated to a depth of 0.3 m with a modified International Harvester model 55 chisel plough. Continuous cropping CT treatments at both sites and NT treatments at Ellerslie received another application of Glyphosate ten days before seeding in the spring. CT plots were cultivated prior to seeding, using a sweep chisel cultivator and harrows. DT treatments at Breton required an additional tillage with a rotary cultivator to break down the large clods which resulted from deep cultivation in the previous year.

2.2.4 Soil Water and Water Use Efficiency

The water use of each treatment during each crop season was determined using the water balance method. Precipitation data were collected at on-site meteorological stations. At the Breton site, technical difficulties with the on-site meteorological station made it necessary to fill in some missing precipitation data with data from the Atmospheric Environmental Service's station located within the town of Breton, 5 km from the study site. An estimate of ET was obtained by measuring the change in soil water content in each treatment during the growing season.

Volumetric soil water content was measured by the neutron attenuation method with a 503DR probe (Campbell Scientific Nuclear Corporation, Martinez, CA). This probe emits neutrons which are readily reflected by the hydrogen atoms in water. The ratio between a standard count and a measurement (called the count ratio [CR]) is used to calculate the amount of soil water present. For this application, a 16 second counting time was found to provide consistent readings and a calibration curve was established at the Ellerslie site by comparing the count ratio with volumetric water readings. Each time the probe was used a standard count was taken to establish the number of emitted neutrons for the count ratio. An aluminum tube 55 mm in diameter and 0.9 m in length was installed to a depth of 0.8 m near the center of each plot providing access for the probe to measure soil water content. These tubes were removed prior to and replaced after seeding and tillage operations. Two 16 second counts were taken at each of 7 depths (0.15 m, 0.25 m, 0.35 m, 0.45 m, 0.55 m, 0.65 m and 0.75 m) in each plot to determine the soil water content with depth. Reading dates over the four-year experimental period are given in Table 2.4.

Water content in the upper 0.8 m of each treatment for each sampling date was calculated by multiplying the water content in each layer by the layer thickness and summing these values. Sampling dates closest to the crop's emergence and harvest were used as the respective start and end points for water use calculations (Table 2.4). At Ellerslie, estimates of growing season ET were calculated under the assumption that the runoff was not significant in the water balance because of the very slight slope, adequate surface residue cover, and adequate infiltration characteristics of this soil (Singh 1991). In addition, Verma and Toogood (1969) determined that the maximum rainfall intensities at Ellerslie would not generate runoff unless surface sealing had occurred. The subsurface drainage component of the water balance was assumed to be negligible for this study. Estimates of the of subsurface drainage at Ellerslie, using hydraulic conductivity values of surface soils from Chapter 3, indicate that this rate would be at most 3 mm yr^{-1}. However, Maulé and Chanasyk (1987) estimated that the drainage component of the water balance was as high as 95 mm during a growing season with 284 mm of precipitation at a nearby site cropped to barley. Exclusion of this parameter may have lead to over-estimation of ET.

At Breton, Izaurralde et al. (1994) recognized that runoff is a significant part of the water balance. An estimate of this parameter was made by simulating runoff on a whole-site basis using the Erosion Productivity Impact Calculator (EPIC) computer model version 3090 (Agricultural Research Service; United States Department of Agriculture). This model was used previously to simulate barley yield and water balance parameters for the Breton site (Izaurralde *et al.* 1993), and resulted in realistic predictions of crop yield and soil water when compared to measured data. Inputs for the model included data for soil parameters and barley crop characteristics obtained from Izaurralde et al. (1993). Long-term meteorological data were obtained from the Atmospheric Environmental Service (1993), while daily weather input files for 1989 to 1992 were constructed from a combination of on-site meteorological readings and Atmospheric Environmental Service data. The model uses the Penman equation (Penman 1948) as modified by Monteith (1965) to estimate the potential ET of a small (< 1 ha) area. Runoff is estimated by using a modified curve-number technique developed by the Soil Conservation Service (U. S. Department of Agriculture, 1972). This estimate relies on the proper selection of the curve number to accurately estimate the amount of runoff for a given amount and intensity of precipitation. The percolation component of the model estimates downward water flow through soil layers. The main inputs for this model component are antecedent soil moisture, soil water holding parameters, and soil physical properties. Plant transpiration is calculated by a subroutine in the model which uses leaf area index as its main input. Further description of these components is given by Sharpley and Williams (1990). One value for runoff (in mm) was obtained from the model for each growing season, and subtracted from the precipitation value in the water balance equation. Values for subsurface drainage obtained from the model were very small and were therefore not included in the on-site hydrologic balance. Having calculated the main components of the water balance, estimates of ET for each crop and growing season were obtained. Using the dry matter yield data for each crop year, Equation 2.1 was used to calculate the WUE for each treatment.

2.2.5 Statistical Analyses

Analyses of variance for soil water, ET, water use efficiency and crop dry matter data were performed using the General Linear Models (GLM) procedure in SAS (SAS Institute, 1985) using a randomized complete block design. Mean separations were performed within the General Linear Models procedure using the PDIFF (probable difference) subcommand or by creating contrasts among treatments. Data sets were checked for normality using the W test (Shapiro and Wilk 1965) within the Univariate Procedure in SAS, and for homogeneity of variances using Barlett's test (Sokal and Rohlf 1981) written in SAS source code by C. Nguyen.

2.3 Results and Discussion

2.3.1 Meteorological and Cropping Conditions

Monthly precipitation and mean monthly temperature values over four years, along with the long-term averages for each site are presented in Figs. 2.3 to 2.6. Precipitation values for the growing seasons from 1989 to 1992 at Breton were 496, 396, 373, and 176 mm while the long-term average precipitation value for this station is 324 mm. These values at Ellerslie were 279, 308, 271, and 168 mm with a long-term average of 279 mm.

Cropping conditions were favorable in the first three years at both sites with the notable exception of those for barley and barley-field pea intercrop treatments at Breton in 1991, which suffered from a combination of root waterlogging and compaction of the soil by seeding equipment early in the season. These effects were noted in the field but could not be quantified. The below normal precipitation received at both sites in 1992 lowered crop yields.

2.3.2 Climate and Cropping Treatment Effects on Soil Water

Figures 2.7 and 2.8 illustrate the trend of soil water in the upper 0.8 m of the soil over four years. There was an overall decreasing trend in soil water at both sites. These figures also illustrate distinct periods of soil water depletion and recharge, each pair roughly following an annual cycle. Some of the variation in soil water content over four years in the upper 0.8 m of the profile can be accounted for by cropping treatment and by time at both sites.

Temporal variability in soil water was accounted for mainly by differences in climatic factors such as precipitation and temperature. These factors affect soil water content and distribution by determining crop growth timing and rate, and by altering infiltration. Other sources of temporal variability in soil water may have been introduced by altering management practices from year to year, or by differences in plant genetics and nutrient status. Positive correlation exists between precipitation and soil water for the growing seasons (Table 2.5), indicating that the decreasing trend may be attributed mainly to fluctuations in seasonal precipitation rather than cropping factors.

Distributional changes to soil water over time were attributed to infiltration and ET. At both sites the greatest changes in soil water over time occurred in the upper soil layer (measured at 0.05 m to 0.3 m). Within this layer there was a 28% relative difference between the growing season with the most soil water (a mean of 86 mm in 1989) and the growing season with the least (a mean of 62 mm in 1992) at Ellerslie. There was a 21% change between these intervals at Breton (89 mm in 1989 and 73 mm in 1992). The soil layer from 0.3 m to 0.6 m showed the least change over time at both sites. Fluctuations of soil water in the upper layer were attributed to infiltration, plant transpiration, and surface evaporation; processes which are all concentrated in this part of the soil. Fluctuations in the lower soil layers may also be attributed to ET, but to a lesser extent than in the surface layer. Since barley roots have the ability to penetrate the soil to depths of greater than 1 m in loamy soils (Madsen 1985), plants could contribute to ET withdrawal at the 0.6 m to 0.8 m depth interval. Izaurralde *et al.* (1993) found that the majority of root dry matter in barley and faba bean treatments at these sites was in the upper 0.14 m of the soil and that only small amounts of root material (<20 g m^2) were present below 0.28 m, indicating that water extraction below this depth would be minimal. However, Maulé and Chanasyk (1987) reported that water was extracted by barley roots to a depth of 0.9 m at a nearby site, but that extraction did not take place at this depth until late in the growing season. Increases in soil water in the lower depth intervals may have been caused by infiltration and occasionally through water table fluctuations from below. Field observations at Breton early in the growing seasons of 1990 and 1991 noted that there was evidence that the water table had reached a depth of 0.7 m in some plots within the experiment. During these periods, subsurface flow may have contributed to the hydrologic balance at this site.

The effect of cropping treatments on soil water over the study period were significant at both sites. Cropping treatment effects can be divided into two types: crop effects and tillage system effects. At Ellerslie, differences in soil water due to crop effects over the four-year period were observed mainly in the surface soil layer (0.05 m to 0.3 m) and the 0.3 m to 0.6 m layer (Table 2.6). In the surface layer faba bean had less water than continuous barley treatments where N was added and fescue crops had significantly lower soil water compared to the other crops. Continuous barley crops where N was added had greater soil water than those without added N in this layer. This result may be attributed to the increased surface evaporation in the unfertilized treatments, where the crop canopy was not as well developed as in treatments where N had been added.

Tillage system effects within annual crops at Ellerslie were observed in the surface and middle soil layers (Table 2.7). There was a significant difference between the NT system and the CT system within both of these layers. This overall difference is attributed to differences between the CT-low input and NT management systems of rotation crops. Specifically, contrast analysis revealed that there was less soil water in CT-LI barley and intercrop treatments compared to similar NT treatments. A comparison of the vertical distributions for these systems in 1990 and early 1991 is shown in Fig. 2.9. Both systems had similar water content distributions from 0.45 m to 0.75 m during this time. Early in the growing season of 1990 (up until July 8), water contents of the two systems were similar at 0.15 m, but diverged at the 0.25 m and

0.35 m depths. Toward the end of the growing season and thereafter, the two systems diverged in the upper two depth increments. The distribution in the spring of 1991 was similar to that in the spring of 1990. The interactive effect of tillage and weed control between these two systems may have accounted for differences observed in soil water between the treatments (Chapters 3 and 4).

Cropping treatment effects at Breton were observed in all soil layers over the experimental period. The crop effects at this site (Table 2.8) included differences between faba bean and all barley treatments in the lower two soil layers. Faba bean treatments contained less soil water than continuous barley treatments without added N in all layers, and less soil water than barley after intercrop in the lower two layers. Faba bean also had less water than continuous barley with added N in the lowest soil layer. Crop comparisons not including faba bean showed effects only in the upper two soil layers. Here, soil water in continuous barley without added N was higher than in barley grown in rotation after faba bean. Soil water in intercrop treatments also differed from continuous barley without added N in the upper two soil layers. Differences in soil water between tillage systems at Breton (Table 2.9) were observed only within continuous barley, where soil water in DT treatments in the surface layer was less than in the CT treatments. Improved drainage under DT may have reduced surface soil water in these treatments.

The effects of cropping systems on soil water are shown in Tables 2.6 and 2.8. At Ellerslie, no overall differences in soil water between the continuous annual cropping system and the rotation annual cropping system were observed, despite a difference in the upper soil layer between continuous barley treatments and faba bean treatments. At both sites there was less soil water in continuous forage treatments than in the continuous annual crops in the upper soil layer. At Breton, there were differences between the annual cropping systems at all depths. Here, soil water in continuous cropped barley was greater than in three of the annual rotation crops in at least one depth interval. The differences in management between continuous and rotation annual crops at Breton may account for some of the observed differences in soil water. Firstly, the water demand and subsequently the ET of the rotation crops may have differed from that of the continuous crops because of the crops used and the nature of nutrient cycling within the systems. Secondly, weed control methods between the two systems differed. The continuous cropping system used herbicides and tillage as weed control methods, while the rotation system used tillage and natural crop competition. More detailed discussion of the effects of these differing management strategies are given in Chapter 4.

Changes in the vertical distribution of soil water content between the three cropping systems in two climatically contrasting growing seasons at each site are shown in Figs. 2.10 and 2.11. At Breton the distribution of soil water is similar in all instances, with the lowest water contents at the 0.15 m depth and the greatest water contents at the 0.75 m depth. Distribution of water is relatively uniform at the beginning of each growing season from 0.25 m downward. As each growing season progresses, the water content decreases in the upper profile, while remaining relatively constant at depth. One exception to this is the distribution near the end of the growing season of 1992 (a year in which precipitation was well below normal), where soil water at the 0.75 m depth was also depleted compared to the beginning of the growing season. The three cropping systems appear to have similar distributions and water contents in both growing seasons. Volumetric water contents of greater than 0.4 m^3 m^{-3} in the lower four depths in 1989 are indicative of poor drainage conditions during this time. Subsurface flows due to a high water table may influence the hydrologic balance during such times.

At Ellerslie distributions of soil water for the growing season of 1989, during which precipitation equaled the long term normal, are relatively uniform with depth. Precipitation during the growing season of 1992 was 111 mm below normal. In June the greatest water contents were recorded at the 0.15 m and 0.25 m depths. In early July the distribution was roughly uniform, and by the end the growing season, water contents in the upper 0.35 m were lower than those at greater depths. Differences in soil water distribution between the cropping systems was apparent in the early growing season of 1989, when there was some divergence in water content in the upper 0.35 m of the soil. At this time the continuous forage cropping system had the lowest water content and the rotation annual system the most. In the middle of this season the three cropping systems had similar soil water contents, and by the end of the season the continuous forage system had the greatest water content and the other two systems had roughly similar soil water contents. The change in the continuous fescue cropping system over this season from lowest to highest water content may be due to the difference in its growing season with respect to that of annual crops. Fescue begins to transpire water earlier than annual crops and is harvested in early July. The period from mid-July to mid-August may be a recharge period for this crop, since the leaf area for transpiration has been reduced by cutting.

2.3.3 Soil Water Recharge Dynamics

Soil water recharge occurs during periods when infiltration of water into the soil exceeds the evaporative demand: i.e.: The left side of the water balance equation (P

-R) exceeds ET - D resulting in an increase in ΔW. the slopes of the lines connecting points of soil water measurements in Figs 2.7 and 2.8 represent changes in ΔW with time. The accuracy of these estimates depends on the actual rate of change in W compared to the estimate, since ΔW is a continuous variable, and the estimates are made based on discrete points. By using the soil water measurements connected by lines of positive slope as maxima and minima for each recharge period, an estimate of recharge was obtained. The accuracy of this estimate cannot be confirmed, however, since the actual maximum and minimum amounts of soil water within each time period are not known. At Ellerslie, four distinct recharge periods were identified, while at Breton there were five (Tables 2.10 and 2.11). At both sites the treatment effects on recharge depended on the recharge period. The greatest recharge occurred in the period during the fall and winter of 1992-1993 after the growing season with the least precipitation of the four years. At Ellerslie, the continuous forage cropping system had the greatest recharge in three of the four periods. Recharge from October 17/1989 to July 8/1990 was similar in all cropping systems. The rotation annual and continuous annual cropping systems had similar soil water increase in all recharge periods. At Breton, the continuous forage cropping system had the greatest soil water increase in three of the five time periods (July 24/1989 to August 27/1989, September 3/1990 to May 5/1991 and August 8/1992 to April 27/1993). Rotation annual crops had the greatest recharge in the May 6/1990 to June 21/1990 and December 12/1991 to June 8/1991 time periods. Soil water increases in individual crop-tillage treatments at each site were not significant (analysis not shown) since they varied with each time period.

2.3.4 Cropping Treatment Effects on Evapotranspiration and Water Use Efficiency

As with soil water recharge, the calculation of growing season ET relied on determining relative changes in soil water with time. Using each growing season as a time period, ET was determined by calculating changes in total soil water (ΔW) for each cropping treatment. The continuous forage (creeping red fescue) cropping system was not included in ET calculations because its growing seasons did not correspond to those of annual crops, making seasonal ET and WUE comparisons difficult.

The mean seasonal ET at Ellerslie over four years was 293 mm. Faba bean had the greatest ET of all cropping treatments (Table 2.12), similar to that of rotation barley grown after intercrop, but significantly greater than all other treatments. Intercrop and continuous barley without added nitrogen had the lowest ET values over the four years. Tillage system influence on ET was significant only in barley treatments grown in rotation after faba bean (Table 2.13). In this case the NT tillage system had a significantly lower ET than the CT treatment (274 mm vs. 306 mm). ET values in the continuous annual and rotation annual cropping systems at this site were the same.

At Breton, the calculation of ET relied on the estimation of runoff by the EPIC computer model. The runoff curve number has been shown to be one of the most sensitive parameters influencing this estimation in EPIC (Sharpley and Williams 1990). Altering this input by one value changed the runoff estimates by roughly 20%. For this site a curve number of 84 was selected, giving estimated values of runoff for growing seasons from 1989 to 1992 of 53 mm, 127 mm, 107 mm and 5 mm respectively. Cropping treatment ET values which incorporate the runoff losses are presented in Table 2.14. As with Ellerslie, faba bean crops had the greatest mean ET. Barley grown in rotation after faba bean and continuous barley without added N had the lowest ET values. There was no overall difference in the ET of tillage treatments (Table 2.15), but there were individual differences in ET between tillage treatments. Barley-field pea intercrop treatments under deep tillage had a significantly lower ET than those under CT (267 mm vs. 294 mm). There was no difference in ET between the two cropping systems at this site.

Water use efficiency values averaged over the four year period for each cropping treatment are given in Tables 2.12 and 2.14. Values for above-ground dry matter yield are also included in these tables but are discussed elsewhere (Choudhary *et al.* 1993). Cropping treatment had a significant effect on WUE at both sites. At Ellerslie, continuous barley with added N had the greatest WUE, while faba bean had the lowest. Other cropping treatments were not different from each other. Tillage system effects on WUE were significant (Table 2.13). Overall, WUE in NT treatments was greater than that in the CT system, due mainly to the differences in WUE between the two tillage systems within the rotation cropping system. All rotation crops except for faba bean had significantly greater water use efficiency under NT than under CT. The cropping system also affected water use efficiency, with the WUE of the continuous barley system approximately 17% greater than that of the rotation system.

Water use efficiency among cropping treatments at Breton was unlike those at Ellerslie. Faba bean had the greatest WUE at the Breton site, while the two barley treatments grown in rotation and the continuous barley without nitrogen had the lowest. There were no effects due to the cropping system on WUE, and the only effect due to tillage treatments was within the faba bean cropping treatment (Table 2.15).

2.3.5 General Discussion

Effects of cropping treatment, cropping system, and tillage on soil water dynamics, ET and water use efficiency were observed at both sites. Changes in soil water with time were found to be reliant mainly on precipitation during growing seasons, but the effects of precipitation and temperature on soil water during the non-growing season periods were not discussed, because of the lack of winter soil water data and the complex effects which snow-water-temperature interactions have on the hydrologic balance.

Cropping system effects on soil water at Ellerslie were confined to the upper 0.6 m of the soil. In that part of the profile annual cropping systems had similar soil water contents, while the continuous forage system had less soil water than both treatments in the 0.05 m to 0.3 m layer and less than the continuous cropping system in the 0.3 m to 0.6 m part of the profile. Soil water at Breton was affected by cropping system to a depth of at least 0.8 m. Continuous annual crops had the greatest soil water in all soil layers. There may be several reasons for reduced soil water under creeping red fescue, Firstly, the growing season for fescue was longer than that of annual crops, resulting in a longer period of, and possibly a greater amount of ET. Secondly, the below ground biomass production of fescue has been shown to be greater than that of barley, field pea and faba bean (Izaurralde *et al.* 1993). Since the roots of fescue also tend to be concentrated in the upper 0.6 m of the soil (Partridge 1941; Izaurralde 1993), they may draw only small amounts of water from lower layers, while drawing water more efficiently than other crops from the upper part of the profile. Thirdly, a build-up of litter from decomposing plants has been shown to intercept rainfall from small precipitation events and prevent water from entering the soil in some grassland ecosystems (Couturier and Ripley 1973). Increase in soil water during most of the recharge periods was found to be greatest in continuous grass crops, indicating that even though soil water was lower overall in this system the recharge brought soil water status to an equivalent level of the other treatments at some time each year. This is illustrated in the soil water distribution at Breton in 1989 (Fig. 2.13) and in 1992 at Ellerslie (Fig. 2.14).

The differences in soil water between annual cropping systems at Breton are evident throughout the sampled depth (0.05 m 0.8 m). Continuous annual crops had greater soil water in all layers over the four-year period than rotation annual crops. This may be due to the inclusion of faba bean in the rotation. Krogman *et al.* (1980) found that faba bean used water at a greater rate than did wheat under well irrigated conditions. At the Breton site, where soil water surpluses are common, faba bean may have drawn more soil water than other cropping treatments, thereby reducing the amount of soil water in the rotation cropping system. At Ellerslie no differences in soil water between cropping systems were observed, indicating that water surpluses may be less common at this site, and that differences in water use between individual crops within the rotation are not large enough to affect the cropping system.

Differences in ET between cropping treatments were seen at both sites, but there were no effects of ET on the cropping system, even though faba bean, as part of the rotation system, had the greatest ET at both locations. Mean ET values for barley crops over four years was 290 mm at Ellerslie and 264 mm at Breton. These values compare favorably to a growing-season ET for barley of 254 mm calculated by Maulé and Chanasyk (1986) in a growing season of near-normal precipitation at the Ellerslie site. Values for ET of faba bean were 311 mm and 282 mm over four years for Ellerslie and Breton respectively. These values are lower than the value of 407 mm recorded for faba bean at Ellerslie in the 1987 growing season (Izaurralde *et al.* 1994). The difference observed between ET of faba bean in this experiment and the previous one may be due in part to the drought conditions which occurred in 1992, when ET was low across all crops.

Water use efficiency values for each site were calculated based on the estimated ET values and the harvested above-ground biomass. A regression of these two components on WUE was performed in order to determine the relative contribution of each to the variability of WUE at each site (Table 2.16). ET alone as a regression parameter accounted for 49% of the total variability in WUE at Ellerslie, while at Breton this figure was 17%. DM alone as a regression parameter accounted for 44% of the total variability in WUE at Ellerslie. At Breton this figure was 82%. These figures suggest that at Ellerslie, the contribution of each parameter to WUE was roughly equal, while at Breton above ground dry matter was the dominant factor affecting the variability of WUE. There is a positive linear correlation between dry matter and WUE at both sites. This type of correlation was discussed by Viets (1962). He reasoned that if such a correlation existed, then ET was not a limiting factor in yield, and that other factors such as fertility were controlling yield. This is likely the case at Breton, where status of several nutrients is known to be low (Cannon *et al.* 1984) and soil water is not limiting to plant growth in most years. At Ellerslie, low fertility may also a limiting factor in yield, but the greater contribution of ET to WUE variability than at Breton indicates that water may also be limiting yield.

The WUE of the rotation annual cropping systems at Ellerslie is lower than that of the continuous cropping system. This difference can be attributed to the low WUE of faba bean in the rotation and high WUE of continuous barley with added N. Faba bean had the greatest ET, but the least biomass production of all cropping treatments. At Breton, the WUE of faba bean was the highest among the cropping treatments, while barley-field pea intercrop and continuous barley with added N had the next-highest values for WUE. These findings can be explained using the information from Table 2.16. In this case, the contribution of N, either from added fertilizer or biological fixation would increase DM and thus would have a greater effect on WUE at this site than a reduction of ET would. This would result in higher WUE values for faba bean, intercrop and barley with added N as compared to crops without N contributions. No differences in WUE between cropping systems were found at this site.

Differences in ET and WUE between tillage treatments at Ellerslie were all within the rotation cropping system. The cropping treatments of barley grown after faba bean differed in ET and WUE between the tillage management systems, while barley grown after intercrop and intercrop treatments differed in WUE only. Since the tillage-management systems at Ellerslie differ in tillage, weed control and residue management, it is difficult to determine which factors are significant contributors to the difference in WUE. Singh (1991) found that there were higher infiltration rates and higher amounts of soil water in NT treatments than in CT treatments under barley in a nearby experiment, but did not conclude that this difference would result in greater amounts of plant available water. Over the whole rotation, greater soil water under NT cannot account for differences in WUE, because ET was constant for both tillage systems. Tillage and weed control effects on ET and WUE will be discussed in greater detail in the following chapters. Tillage treatment effects on ET at Breton were limited to differences between DT intercrop and CT intercrop. Mean values for ET in intercrop treatments under CT were greater than under DT. Changes in soil physical properties due to the DT treatment may have altered the water holding or transmission properties of the soil at the surface. Field pea plants are susceptible to waterlogging (Jackson 1980) which might occur under this type of profile modification. The only difference between tillage systems in WUE was in the faba bean cropping treatment. Faba bean has been shown to respond to modification of the rooting zone by deep tillage with an increase in WUE (Rowse and Stone 1981, Rengasamy and Reid 1993). This increase may be due either to improved root penetration into lower, previously inaccessible parts of the soil profile, or by improved nodulation and N fixation.

2.4 Conclusions

The four-year study found that soil water from 0.05 to 0.8 m was affected by cropping system at Ellerslie and Breton. Differences in soil water between growing seasons were accounted for by climatic factors at both sites, while differences between cropping systems varied with site and depth. At Ellerslie, cropping system effects on soil water were limited to the 0.05 m to 0.3 m soil layer. Here, annual cropping systems had similar amounts of soil water, while the continuous forage system had less water overall. At Breton, soil water differed between the three cropping systems through the sampled depth with continuous annual crop > rotation annual crops > continuous forage crop. Seasonal evapotranspiration of the faba bean cropping treatment was greatest at both sites, but no cropping system differences in ET were observed. WUE at Ellerslie was affected by both ET and above ground dry matter yield, indicating that both soil water and fertility were limiting plant production. At Breton, dry matter production was the dominant influence on WUE, indicating that fertility, rather than soil water was limiting plant production. Tillage system effects on WUE were limited to the rotation annual cropping system at Ellerslie and to faba bean treatments at Breton. The use of water by the alternative annual cropping system at the Ellerslie site was not as efficient as the conventional system in terms of water used per unit dry matter production. At Breton, conventional and alternative cropping systems performed equally in use of water resources.

Table 2.1 Selected soil properties at Ellerslie and Breton (Adapted from Crown and Greenlee, 1978.)

	Ellerslie					Breton				
Horizon	Ap	Ae	Bt_1	Bt_2	Ccag	Ap	Ae	Bt_1	Bt_2	BC
Horizon Depth (cm)	0-30	30-37	37-87	87-113	113+	0-24	24-32	32-58	58-95	95+
Textural Class	SiL	SiL	L	CL	SiL	SiL	L	CL	CL	CL
Bulk Density (Mg m^{-3})*	0.9	1.1	1.6	-	-	1.1	1.3	1.6	1.6	-
AWHC (m^3 m^{-3})**	0.14	0.13	0.17	-	-	0.24	0.21	0.21	0.21	-
pH (in $CaCl_2$)	6.4	6.2	6.3	7.0	7.5	6.0	5.7	5.2	5.1	5.2
Organic C (g kg^{-1})	52	9	3	3	-	14	4	4	4	-
Organic N (g kg^{-1})	5.0	1.0	0.4	0.4	-	1.2	0.4	0.4	0.4	-
CEC (mmol(+) kg^{-1})	400	160	170	220	-	150	100	250	240	290
$CaCO_3$ (g kg^{-1})	-	-	-	5	41	-	-	-	-	-

* Bulk density values presented by Izaurralde *et al.*, 1993.

** Available water holding capacity between 33 kPa and 1500 kPa.

Table 2.2 Climatic normals for the 1951-1980 period at Ellerslie and at Breton. (Atmospheric Environmental Service,1982).

	Ellerslie	Breton
Mean annual precipitation (mm)	452	547
Mean frost-free days	109	80
Degree days > 5°C	1230	1060
Mean summer temperature* °C	13.8	12.5
Mean winter temperature** °C	-11.8	-9.8

* Mean Daily temperature May 1 to August 31.

**Mean Daily temperature December 1 to March 31.

Table 2.3 Seeding and harvest dates for annual crops at each site.

	Ellerslie		Breton	
Year	Seeding	Harvest	Seeding	Harvest
1989	May 17	Aug 21	May 25	Aug 29
1990	May 23	Aug 22	May 31	Sep10
1991	May 24	Aug 20	May 27	Sep 9
1992	May 13	Aug 18	May 18	Aug 24

Table 2.4 Neutron probe soil water measurement dates for each site from 1989 to 1992.

Ellerslie	Breton
1989	
May 04*	May 07*
Jun 15	Jun 11
Jun 19	Jun 21
Jul 19	Jul 03
Aug 23**	Jul 24
Sep 20	Aug 27**
Oct 17	Sep 21
Nov 21	Oct 18
1990	
Jun 05*	May 16*
Jul 08	Jun 21
Jul 25	Jul 19
Aug 27**	Aug 14
Oct 10	Sep 03**
Nov 18	Oct 08
1991	
May 03*	May 08*
Aug 09**	Aug 08**
Dec 04	Dec 05
1992	
Jun 04*	Jun 08*
Jun 18	Jul 16
Jul 06	Aug 28**
Jul 29	Oct 09
Aug 25**	
Sep 29	

* Indicates the start date for growing season calculations.

**Indicates the ending date for growing season calculations

Table 2.5 Regression results of mean growing season soil water vs. growing season precipitation for 4 years at two sites.

Ellerslie		
R Square	0.96*	
	Coefficient	P-value
Intercept	135	0.005
Precipitation	0.457	0.007

Breton		
R Square	0.99*	
	Coefficient	P-value
Intercept	1.97	0.001
Precipitation	0.005	0.001

* Indicates significance of the overall regression at the 0.05 level of probability.

Table 2.6 Mean soil water at Ellerslie for 4 depth intervals from 1989 to 1992.

Cropping Treatment	Depth Interval (m)			
	0.05-0.3	0.3-0.6	0.6-0.8	0.05-0.8
	mm			
Faba bean	76 b[†]	91 ab	79 ab	246 ab
Intercrop	81 ab	93 ab	79 ab	253 ab
Fescue	74 c	90 b	79 ab	245 ab
Barley After Faba bean	81 ab	90 b	75 ab	245 b
Barley After Intercrop	78 ab	93 ab	81 a	252 ab
Barley Continuous 0N	78 b	94 a	73 b	245 b
Barley Continuous +N	84 a	98 a	80 ab	261 a
Cropping System				
	mm			
Continuous Annual Crop (Barley)	81 a[††]	96 a	77 a	253 a
Rotation Annual Crops	79 a	92 ab	78 a	249 a
Continuous Forage (Red Fescue)	76 b	90 b	79 a	245 a

[†] Cropping treatment means within a column followed by the same letter are not significantly different at the 0.05 level of probability.

[††] Cropping system means within a column followed by the same letter are not significantly different at the 0.05 level of probability.

Table 2.7 Analysis of variance for soil water at Ellerslie for 4 depth intervals from 1989 to 1992 including contrasts of tillage-treatment combinations

		Depth Interval			
		0.05-0.3 m	0.3-0.6 m	0.6-0.8 m	0.05-0.8 m
Source	d.f.	Mean Square			
REP	1	43	117	0	323
TIME	6	2551 **	1661 **	1402 **	14332 **
TIME*REP	6	65	66	60	464
TRT	12	274 **	404 **	244 **	1756 **
TIME*TRT	72	72 *	108 *	84 *	509 *
Contrasts†					
CT VS. NT		*	**	NS	*
CT-R VS. NT-R		**	**	NS	**
CT-C-BA VS. NT-C-BA		NS	NS	NS	NS
CT-BA VS. NT-BA		NS	*	NS	NS
CT-FA VS.NT-FA		NS	NS	NS	NS
CT-IN VS. NT-IN		NS	*	NS	NS
CT-R-BA VS. NT-R-BA		**	*	NS	**
CT-B1 VS. NT-B1		NS	NS	NS	NS
CT-B2 VS. NT-B2		**	NS	NS	*

*, ** indicate significance at the 0.05 and 0.01 probability levels, respectively.

NS = Not Significant

†CT = Conservation Tillage, NT = No Tillage, R = Rotation Cropping System, C = Continuous Cropping System, BA = Barley, FA = Faba bean, IN = Barley/Field Pea Intercrop, B1 = Barley in Rotation After Faba bean, B2 = Barley in Rotation after Intercrop.

Table 2.8 Mean soil water at Breton for 4 depth intervals from 1989 to 1992.

	Depth Interval (m)			
Cropping Treatment	0.05-0.3	0.3-0.6	0.6-0.8	0.05-0.8
	mm			
Faba bean	80 b†	109 c	95 b	283 c
Intercrop	82 b	112 bc	99 ab	291 bc
Fescue	77 c	111 bc	99 ab	286 bc
Barley After Faba bean	80 b	111 bc	99 ab	290 bc
Barley After Intercrop	83 ab	113 ab	102 a	297 abc
Barley Continuous 0N	86 a	116 a	102 a	304 a
Barley Continuous +N	84 ab	112 abc	101 a	298 ab
Cropping System				
	mm			
Continuous Annual Crop (Barley)	85 a††	114 a	102 a	301 a
Rotation Annual Crops	81 b	111 b	98 b	290 b
Continuous Forage (Red Fescue)	77 c	112 ab	99 ab	286 c

†Cropping treatment means within a column followed by the same letter are not significantly different at the 0.05 level of probability.

††Cropping system means within a column followed by the same letter are not significantly different at the 0.05 level of probability.

Table 2.9 Analysis of variance for soil water at Breton for 4 depth intervals from 1989 to 1992 including contrasts of tillage-treatment combinations.

		Depth Interval			
		0.05-0.3 m	0.3-0.6 m	0.6-0.8 m	0.05-0.8 m
Source	d.f.	Mean Square			
REP	1	165	101	43	1009
TIME	6	1159 **	1136 **	1155 **	9510 **
TIME*REP	6	7	7	69	96
TRT	12	145 **	99 **	129 **	945 **
TIME*TRT	72	16	25 *	45	153
Contrasts†					
DT VS. CT		*	NS	NS	NS
DT-R VS. CT-R		NS	NS	NS	NS
DT-CBA VS. CT-CBA		*	NS	NS	*
DT-BA VS. CT-BA		*	NS	NS	NS
DT-FA VS. CT-FA		NS	NS	NS	NS
DT-IN VS. CT-IN		NS	NS	NS	NS
DT-RBA VS. CT-RBA		NS	NS	NS	NS
DT-B1 VS. CT-B1		NS	NS	NS	NS
DT-B2 VS. CT-B2		NS	NS	NS	NS

*, ** indicate significance at the 0.05 and 0.01 probability levels, respectively.

NS = Not Significant

†DT = Deep Tillage, NT = No Tillage, R = Rotation Cropping System, C = Continuous Cropping System, BA = Barley, FA = Faba bean, IN = Barley/Field Pea Intercrop, B1 = Barley in Rotation After Faba bean, B2 = Barley in Rotation after Intercrop.

Table 2.10 Soil water increase from 0.05 m to 0.3 m at Ellerslie during four recharge periods.

		Period			
Cropping Treatment	Tillage System	17/10/89 to 08/07/90	18/11/90 to 03/05/91	04/12/91 to 04/06/92	25/08/92 to 09/05/93
		mm			
Faba bean	CT†	41	40	47	n.e.††
	NT	55	38	34	n.e.
Intercrop	CT	32	56	39	68
	NT	17	54	63	81
Fescue	-	40	61	76	94
Barley	CT	71	47	n.e.	68
After Faba bean	NT	58	55	34	67
Barley	CT	24	57	n.e.	91
After Intercrop	NT	23	45	13	100
Barley	CT	48	36	77	58
Continuous 0N	NT	65	35	13	90
Barley	CT	25	47	35	76
Continuous +N	NT	32	55	55	92
Cropping System					
		mm			
Continuous Annual Crop (Barley)		43	43	45	80
Rotation Annual Crops		42	49	39	80
Continuous Forage (Red Fescue)		40	61	76	94

† CT = Conservation tillage NT = No Tillage.

†† n.e. = no estimate.

Table 2.11 Soil water increase from 0.05 m to 0.3 m at Breton during five recharge periods.

		Period				
Cropping Treatment	Tillage System	24/07/89 to 27/08/89	16/05/90 to 21/06/90	03/09/90 to 08/05/91	04/12/91 to 08/06/92	28/08/92 to 27/04/93
		mm				
Faba bean	DT†	24	22	67	42	46
	CT	62	6	65	39	31
Intercrop	DT	34	25	45	30	33
	CT	45	25	47	34	69
Fescue	-	50	29	56	24	67
Barley	DT	32	28	54	27	31
After Faba bean	CT	24	7	40	-6	68
Barley	DT	26	8	50	31	63
After Intercrop	CT	42	39	32	4	31
Barley	DT	49	10	28	11	52
Continuous 0N	CT	40	28	11	8	35
Barley	DT	24	25	48	26	62
Continuous +N	CT	41	11	22	16	30

Cropping System					
	mm				
Continuous Annual Crops	39	18	27	15	44
Rotation Annual Crops	36	34	50	27	46
Continuous Forage (Red Fescue)	50	29	56	24	67

† DT = Deep tillage.

Table 2.12 Least square means of evapotranspiration, dry matter yield and water use efficiency at Ellerslie from 1989 to 1992.

Cropping Treatment	Evapotranspiration	Dry Matter Yield	Water Use Efficiency
	mm	g m^{-2}	g m^{-2} mm^{-1}
Faba bean	311 a[†]	403 c	1.30 c
Intercrop	285 c	504 b	1.76 b
Barley After Faba bean	286 bc	496 b	1.90 b
Barley After Intercrop	300 ab	476 b	1.71 b
Barley Continuous 0N	285 c	468 b	1.70 b
Barley Continuous +N	287 bc	596 a	2.26 a
Cropping System			
Continuous Annual Crop (Barley)	286 a[††]	532 a	1.98 a
Rotation Annual Crops	296 a	470 b	1.68 b

[†] Cropping treatment means within a column followed by the same letter are not significantly different at the 0.05 level of probability.

[††] Cropping system means within a column followed by the same letter are not significantly different at the 0.05 level of probability.

Table 2.13. Analysis of variance for evapotransipiration, dry matter yield and water use efficiency at Ellerslie from 1989 to 1992 including contrasts of tillage-treatment combinations.

		Evapotranspiration	Dry Matter Yield	Water Use Efficiency
Source	DF	Mean Square		
REP	1	496	2062777	18
TIME	3	188110 **	39823465 **	301 **
TIME*REP	3	718	245268	7
TRT	11	1028 *	4909344 **	93 **
TIME*TRT	33	516	2901485 **	32 **
Coefficient of Variation		6.40	13.50	10.96
Contrasts†				
CT VS. NT		NS	**	**
CT-R VS. NT-R		NS	**	**
CT-C-BA VS. NT-C-BA		NS	*	NS
CT-FA VS.NT-FA		NS	NS	NS
CT-IN VS. NT-IN		NS	NS	**
CT-R-BA VS. NT-R-BA		NS	**	**
CT-B1 VS. NT-B1		*	**	**
CT-B2 VS. NT-B2		NS	**	**

*, ** indicate significance at the 0.05 and 0.01 probability levels, respectively.

†CT = Conservation Tillage, NT = No Tillage, R = Rotation Cropping System, C = Continuous Cropping System, BA = Barley, FA = Faba bean, IN = Barley/Field Pea Intercrop, B1 = Barley in Rotation After Faba bean, B2 = Barley in Rotation after Intercrop.

Table 2.14 Least square means of evapotranspiration, dry matter yield and water use efficiency at Breton from 1989 to 1992.

Cropping Treatment	Evapotranspiration	Dry Matter Yield	Water Use Efficiency
	mm	g m^{-2}	g m^{-2} mm^{-1}
Faba bean	282 a†	612 a	2.18 a
Intercrop	279 ab	405 bc	1.48 bc
Barley After Faba bean	261 c	352 cd	1.33 cd
Barley After Intercrop	265 bc	299 d	1.10 d
Barley Continuous 0N	261 c	321 d	1.22 d
Barley Continuous +N	269 abc	441 b	1.63 b
Cropping System			
Continuous Annual Crop (Barley)	265 a††	381 a	1.43 a
Rotation Annual Crops	272 a	417 a	1.52 a

†Cropping treatment means within a column followed by the same letter are not significantly different at the 0.05 level of probability.

††Cropping system means within a column followed by the same letter are not significantly different at the 0.05 level of probability.

Table 2.15. Analysis of variance for evapotransipiration, dry matter yield and water use efficiency at Breton from 1989 to 1992 including contrasts of tillage-treatment combinations.

		Evapotranspiration	Dry Matter Yield	Water Use Efficiency
Source	DF	Mean Square		
REP	1	1713.294	2367555	0.154302
TIME	3	77556.71 **	36997529 *	2.371051 **
TIME*REP	3	517.283	1131292	0.137217
TRT	11	1042.972 *	10023908 **	1.116354 **
TIME*TRT	33	742.056	3744514 **	0.51354 **
Coefficient of Variation		7.7	22.0	23.9
Contrasts†				
DT VS. CT		NS	NS	NS
DT-R VS. CT-R		NS	NS	NS
DT-CBA VS. CT-CBA		NS	NS	NS
DT-BA VS. CT-BA		NS	NS	NS
DT-FA VS.CT-FA		NS	**	**
DT-IN VS. CT-IN		*	NS	NS
DT-RBA VS. CT-RBA		NS	NS	NS
DT-B1 VS. CT-B1		NS	NS	NS
DT-B2 VS. CT-B2		NS	NS	NS

*, ** indicate significance at the 0.05 and 0.01 probability levels, respectively.

†CT = Conservation Tillage, DT = Deep Tillage, R = Rotation Cropping System, C = Continuous Cropping System, BA = Barley, FA = Faba bean, IN = Barley/Field Pea Intercrop, B1 = Barley in Rotation After Faba bean, B2 = Barley in Rotation after Intercrop.

Table 2.16 Results of Stepwise regression to fit the model WUE = X1(DM)+X2(ET)+X3 where X1, X2 and X3 are regression coefficients.

	Variable entered into model	Regression coefficients	Partial R^2	Total R^2	F	pr<F
Ellerslie	DM	0.0035	0.442	0.442	69.8	0.001
	ET	-0.0055	0.489	0.931	618.0	0.001
Breton	DM	0.0039	0.815	0.815	399.5	0.001
	ET	-0.0057	0.168	0.982	855.7	0.001

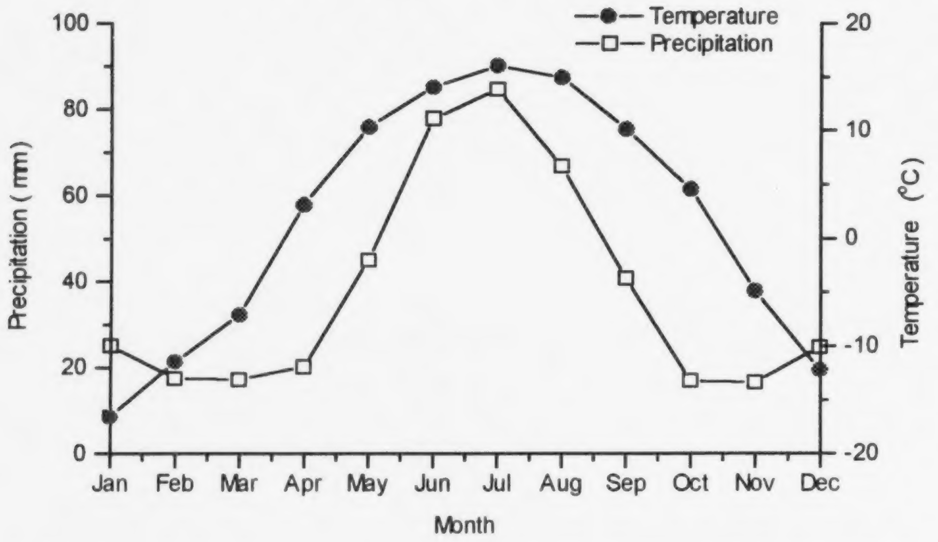

Figure 2.1 Mean temperature and precipitation distribution at Ellerslie 1961-1990 (data from Atmospheric Environmental Service, 1993).

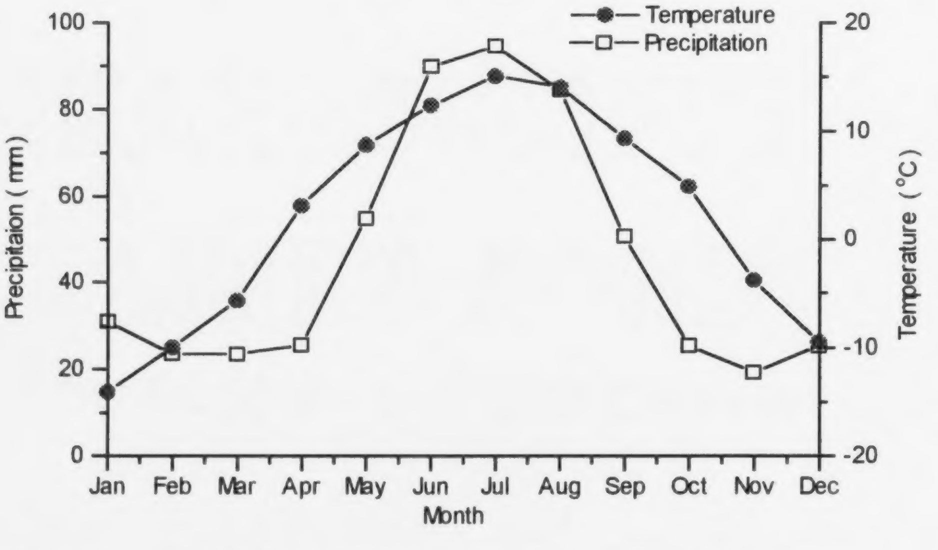

Figure 2.2 Mean temperature distribution at Winfield and mean precipitation distribution at Breton 1961-1990 (data from Atmospheric Environmental Service, 1993).

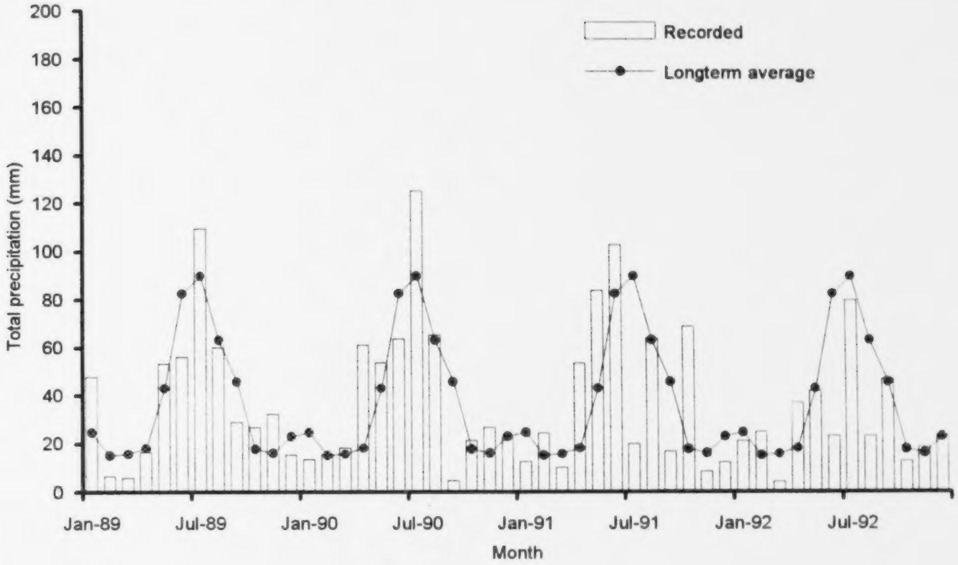

Figure 2.3 Long-term average precipitation at Ellerslie and mean monthly precipitation at Ellerslie over the experimental period.

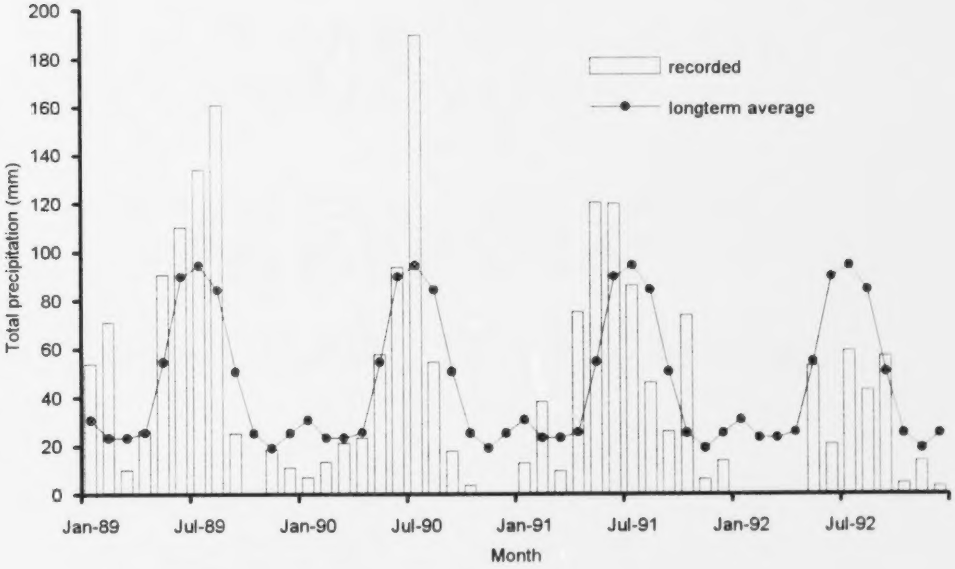

Figure 2.4 Long-term average precipitation at Breton and mean monthly precipitation at Breton over the experimental period.

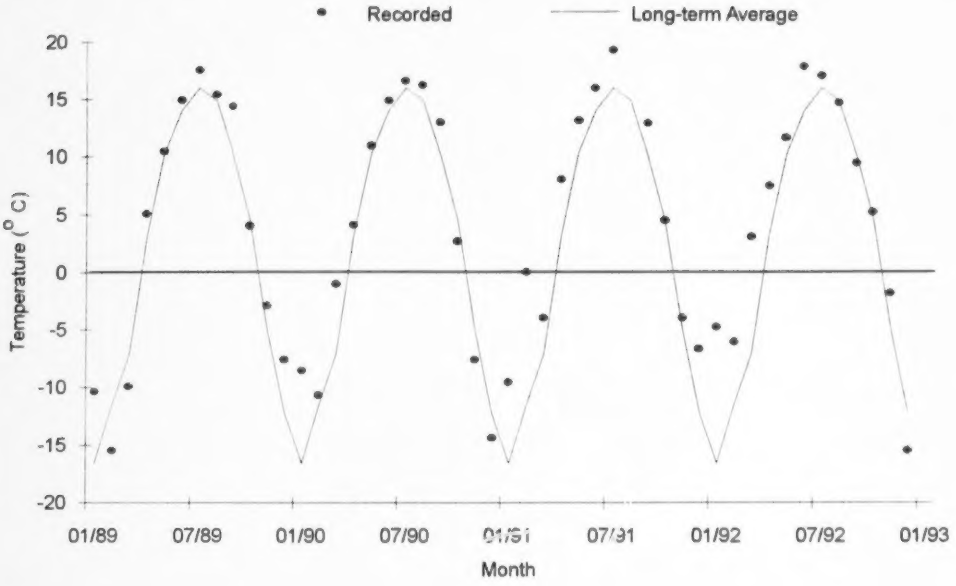

Figure 2.5 Mean monthly temperature at Ellerslie from 1989 to 1993.

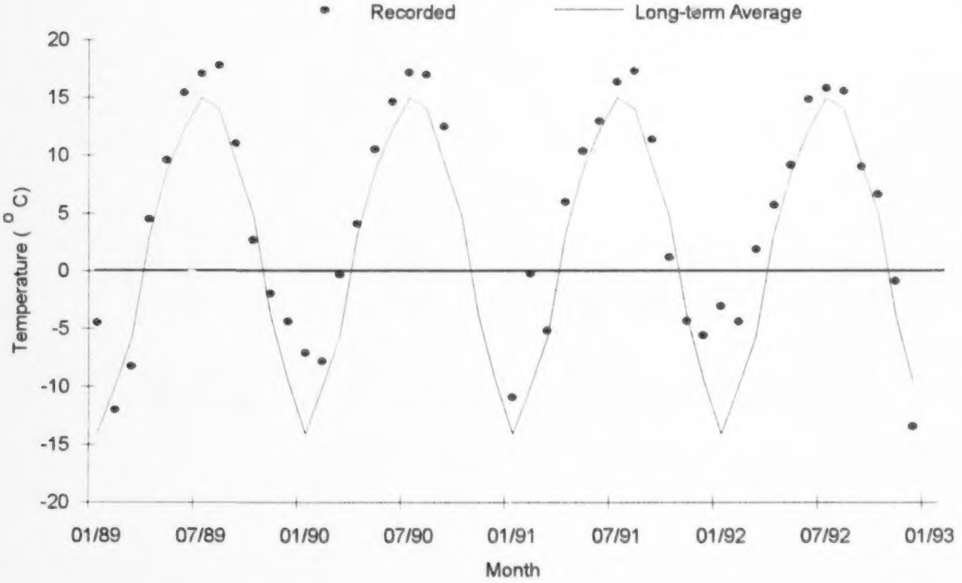

Figure 2.6 Mean monthly temperature at Breton from 1989 to 1993 (Long-term average temperature from nearby Winfield meteorological station).

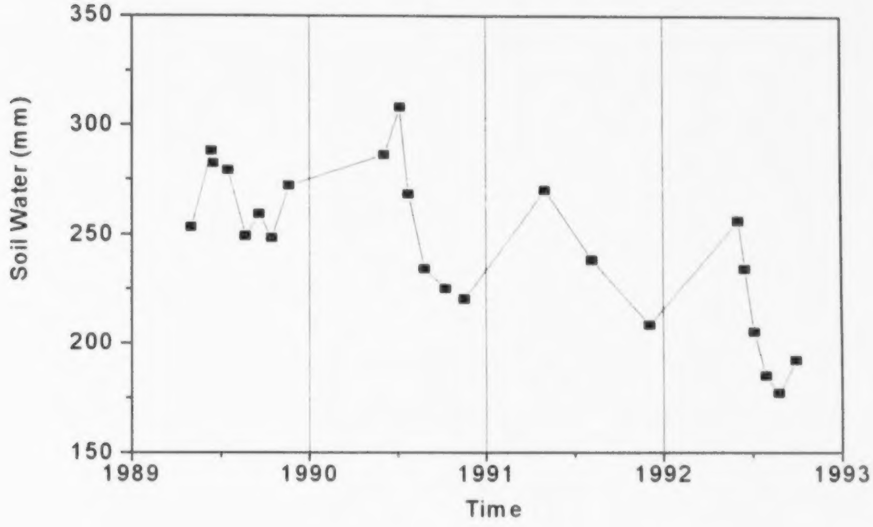

Figure 2.7 Mean soil water from 0.05 m to 0.8 m over a four year period at Ellerslie (1989-1993).

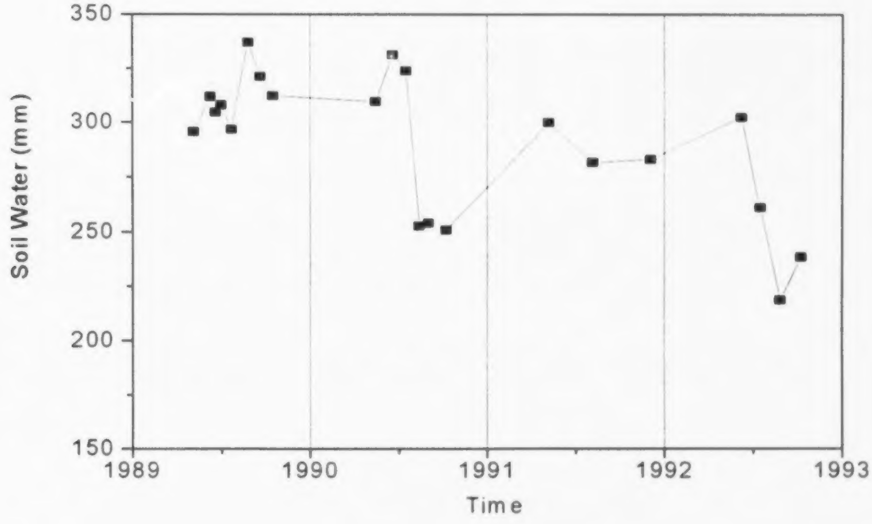

Figure 2.8 Mean soil water from 0.05 m to 0.8 m over a four year period at Breton (1989-1993).

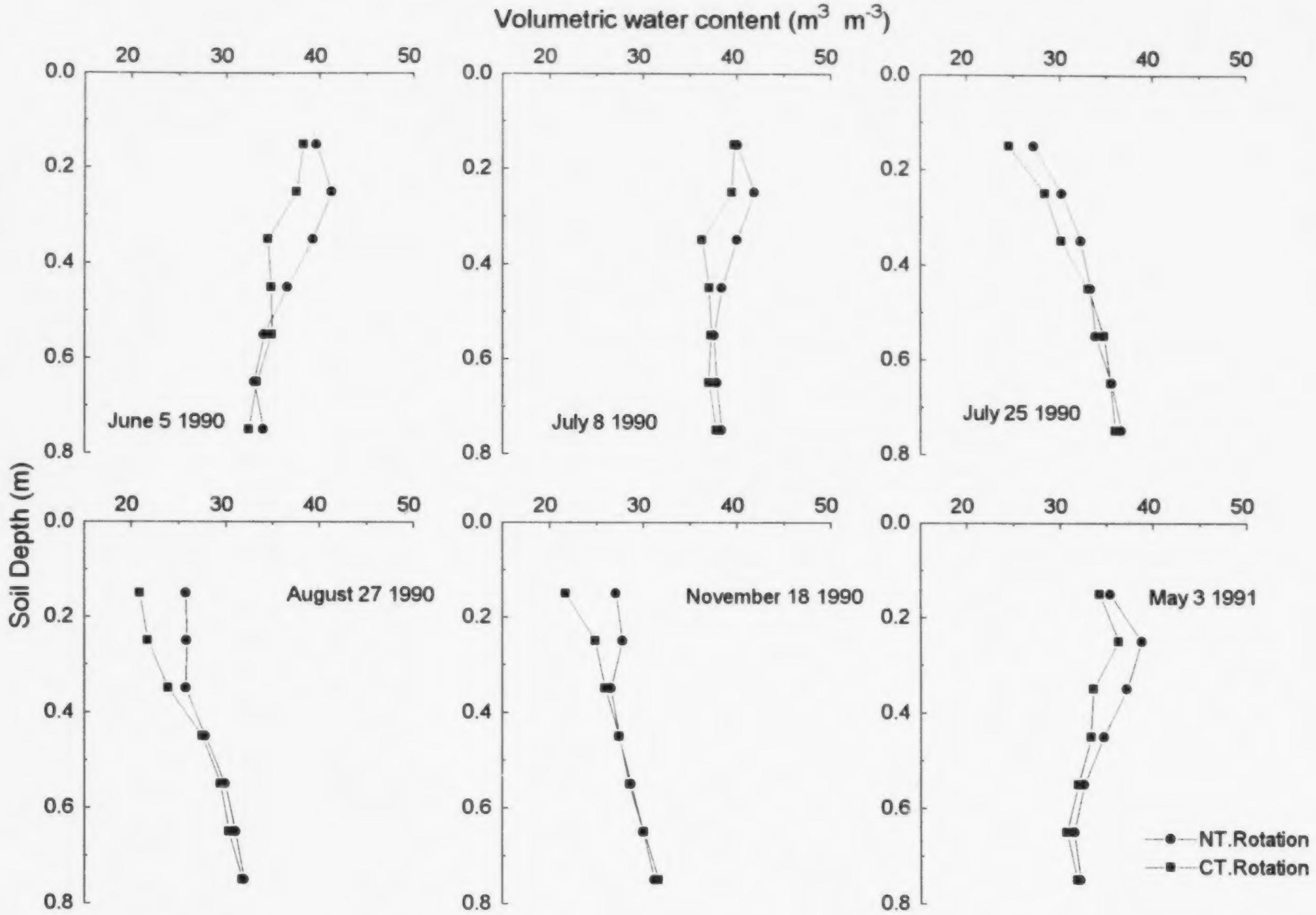

Figure 2.9 Soil water distributions with depth for two tillage treatments within the rotation cropping system at Ellerslie over one calendar year.

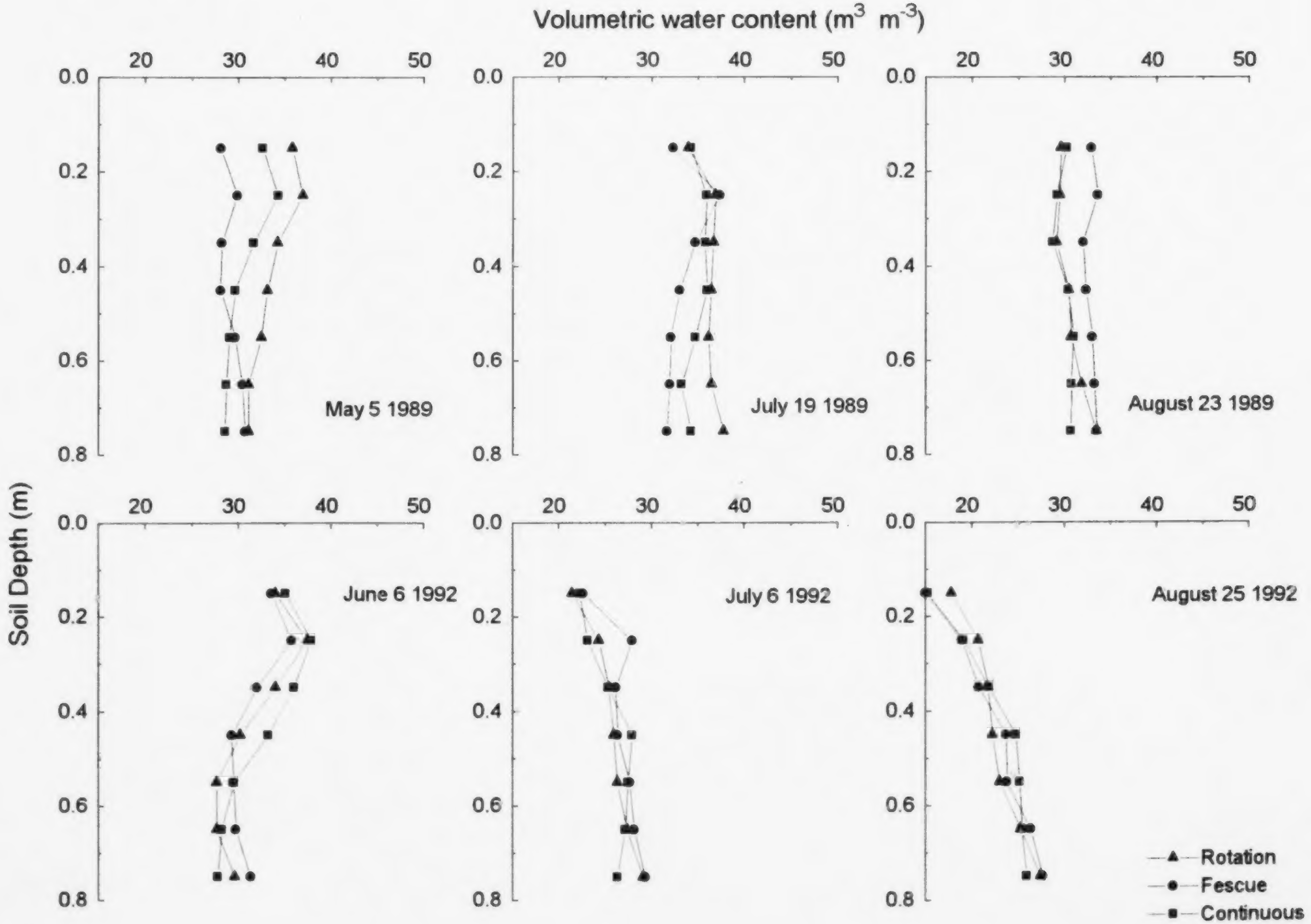

Figure 2.10 Soil water distributions with depth at Ellerslie during two contrasting growing seasons

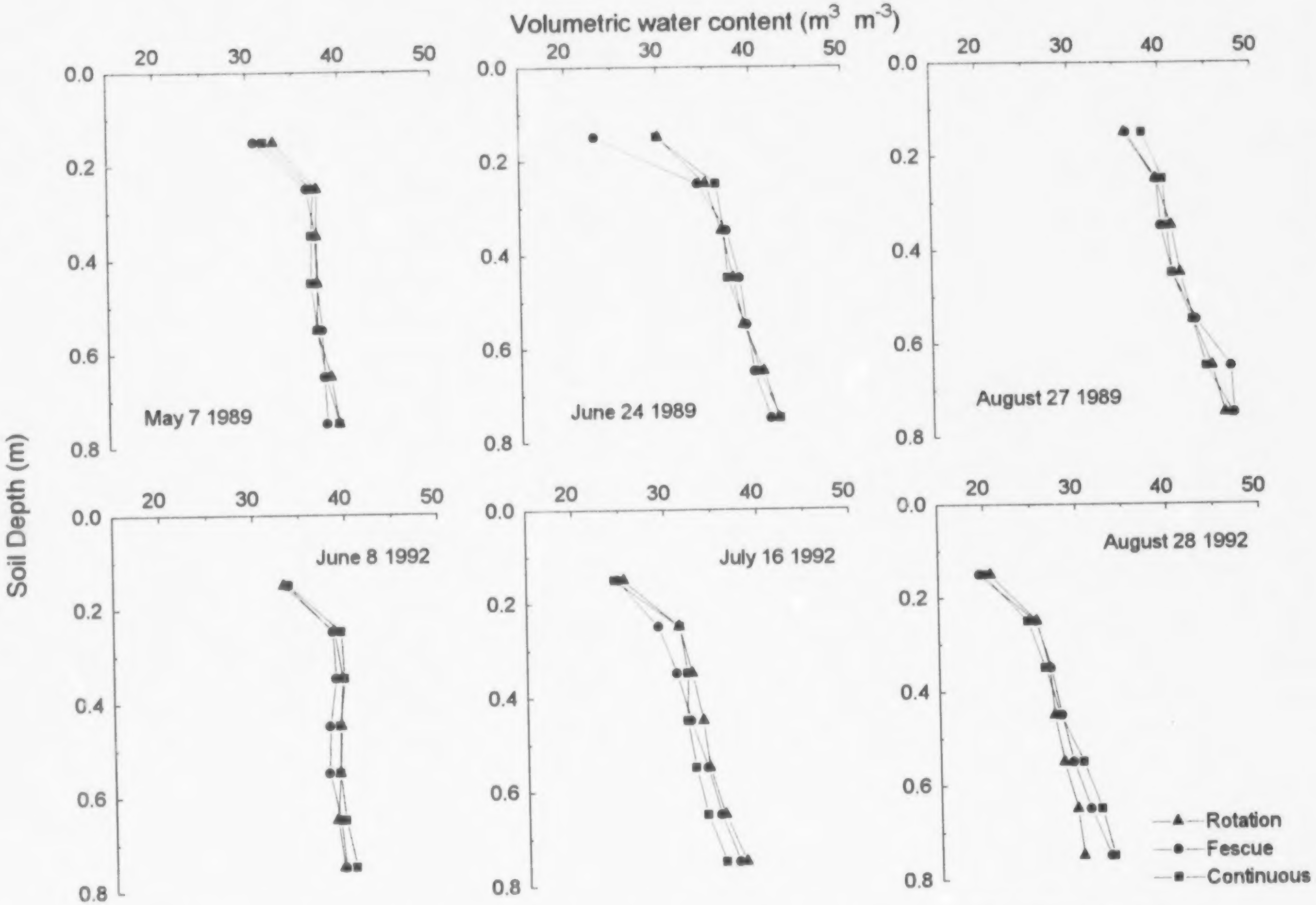

Figure 2.11 Soil water distributions with depth at Breton during two contrasting growing seasons

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Chapter 3

Soil water retention and transmission as affected by tillage at two sites in central Alberta.

3.1 Introduction

The efficient use of water resources is an important consideration in the development of sustainable agricultural systems. Cropping systems which use alternative management such as reduced tillage or deep tillage to improve soil quality must also be examined for their use of water in comparison with conventional methods. The efficiency with which water is used may be changed by favorably altering the hydrologic balance of an area. In rainfed agriculture such changes may include improving the uptake of water by plants, reducing runoff or increasing soil water storage (Tanner and Sinclair 1983). Knowledge of how management factors, such as tillage, affect the transmission and retention of water in the soil is therefore important in determining management strategies for the efficient use of water resources. Some of the physical parameters used in the discussion of soil water include infiltration, water retention, pore size distribution and hydraulic conductivity. These parameters, based on Darcy's law of flow in porous media, provide quantitative means of evaluating management effects.

Most field studies comparing soil water content under reduced tillage or no till (NT) systems with conventional tillage (CT) systems have found higher water contents under NT (Blevins, *et al.* 1971; Johnson, *et al.* 1984; Negi *et al.*, 1981; Zhai *et al.* 1990; Arshad and Dobb 1991; Singh 1991). This difference has often been attributed to reductions in runoff or surface evaporation (Blevins, *et al.* 1971; Dick *et al.* 1989, Arshad and Dobb 1991). Determinations of soil water holding properties have shown an increase in bulk density and corresponding reductions in total porosity in the upper horizons of NT soils (Lindstrom and Onstad 1984; Chang and Lindwall 1990). Opposite results, however were reported by Hermawan and Cameron (1993) in New Zealand. These authors found that the total porosity of a silt loam soil under minimum tillage was greater than under CT. They attributed these findings to the increased aggregate stability and organic matter content developed in the soil under minimum tillage. Changes in total porosity with tillage are often accompanied by changes in pore size distribution (van Ouwewerkerk and Boone 1970; Hill *et al.* 1984). Greenland (1981) classified soil pore sizes according to their function. In this classification pores with effective pore diameters (EPD) in the 50 to 100 μm range are considered transmission-sized pores, used for transporting water, while pores in the 0.5 to 50 μm size range are responsible for water storage. Hill *et al.* (1984) reported that a CT system under corn (*Zea mays* L.) in Iowa had a greater proportion of pores with EPD greater than 30 μm than a reduced tillage (RT) system. They concluded that soil under RT systems would have a greater water storage and lower hydraulic conductivity than those under CT. Similar results were reported by Singh (1991) between NT and CT systems under barley (*Hordeum vulgare* L.) in central Alberta.

Deep tillage (DT) is a method sometimes used in the remediation of soils. The objectives of DT operations are often to enhance crop rooting and subsurface water drainage, or to improve the structure of the surface soil by altering soil texture through inversion. The success of DT to meet these objectives depends on soil properties as well as the type and frequency of the tillage operations (Spoor 1986). Relatively few studies have compared deep tillage methods with conventional tillage methods with respect to water retention and porosity, although reductions in the bulk density of the subsoil of DT treatments have been reported by several researchers (Bolton *et al.*

1981; Chaudhary *et al.* 1985; Johnson *et al.* 1989). Rowse and Stone (1981) found that deep tillage decreased bulk density and improved water retention at a suction of 3 kPa in a sandy clay loam soil in England. In western Canada, DT operations are sometimes used to remediate Solonetzic soils. In Saskatchewan, Grevers and deJong (1992) used image analysis to determine the effects of deep ripping on macroporosity in three soils. They found no differences in bulk density between control and deep ripped treatments, but observed an increase in vertically oriented macropores in the 0.15 to 0.3 m depth interval of a deep ripped clay textured Solonetzic soil. Deep tillage operations have been performed on Luvisolic soils in central Alberta (Cannon *et al.* 1984), but the effects of DT on the physical properties of these soils have not been extensively studied.

Tillage systems may also affect the conductance of water through the soil. The transmission of water is controlled both by pore size and pore continuity. Pore continuity is thought to be promoted by soil faunal activity and shrink-swell processes such as wetting and drying or freeze-thaw cycles (Hamblin 1987). Dick *et al.* (1989) used lysimeters to determine the water transmission characteristics of both conventional and no-tilled Ohio surface soils. They reported that soil water entering the profile and transmitted as leachate was greater in no-tilled treatments than in conventional-tilled treatments. Culley *et al.* (1987) studied tillage effects on soil pore continuity in Minnesota. They concluded that tillage disrupted transmission-sized pores and that treatments that included tillage drained less rapidly than no-tillage treatments where these pores had remained intact. Singh (1991) found that saturated hydraulic conductivity (Ks) and cumulative infiltration were greater in NT treatments than under CT on a Black Chernozem in central Alberta. In contrast, Gantzer and

Blake (1978) and Lindstrom and Onstad (1984) reported lower Ks values in NT treatments than in tilled treatments in the upper 0.15 m of clay loam and loam soils in the United States.

Water movement through soil profiles subject to deep tillage has not been extensively studied. In Australia, Steed *et al.* (1987) used the parameter sorptivity to compare the rate of water infiltration in soils under DT and CT. Soils deep tilled to a depth of 0.4 m had significantly greater sorptivity than the CT treatments. Saturated hydraulic conductivity was compared in DT and CT treatments in Michigan by Johnson *et al.* (1989). They concluded that Ks was not affected by deep tillage in a clay soil, and that the effects of any changes in bulk density or porosity attributed to DT were not long-lasting.

Interpreting the effects of changes in soil physical parameters on crop water use may be difficult due to the interaction between soil, crop, management and climate factors. Several studies have discussed the effects of tillage-induced changes in water retention and movement on crop production. Chang and Lindwall (1990) hypothesized that lower observed values of Ks, bulk density and water holding capacity in NT systems compared to CT, would not affect wheat (*Triticum aestivum* L.) production. Singh (1991) reported that differences in physical parameters between CT and NT did not affect root length or root mass of barley, and that the crop was able to absorb tillage-induced physical changes without affecting root growth. Some researchers have reported that a greater amount of soil water under NT does not affect plant growth (van Ouwerkerk and Boone 1970; Diebert *et al.* 1986), while others reported increases in crop production as a result (Blevins *et al.* 1971; Lafond *et al.* 1992).

In a previous study (Chapter 2) I reported that tillage systems affected the water-use efficiency of crops grown in rotation at two sites in central Alberta. As a supplement to that research, the objective of this study was to determine the effect of soil type and tillage treatment on water retention, pore size distribution and hydraulic conductivity of surface soils. These physical parameters, along with surface soil texture and bulk density may then be used to help interpret observed differences in the water-crop dynamics between tillage systems at each site.

3.2 Materials and Methods

3.2.1 Study Sites: Soil, Climate and Field Studies

Soil samples were collected in 1992 from two crop rotation studies located at sites representing the dominant soil types of agricultural lands in central Alberta. Site 1 is at the University of Alberta Ellerslie Research Station located in Edmonton, AB at 53° 25' N latitude and 113° 33' W longitude and at an elevation of 686 m. The soils at this site are Orthic Black Chernozems of the Malmo silty clay loam series, formed on the fine textured glaciofluvial and glaciolacustrine deposits of glacial Lake Edmonton (Crown and Greenlee 1978). Site 2 is located approximately 110 km south-west of Edmonton on the University of Alberta Breton Plots, near Breton (53° 07' N latitude, 114° 28' W longitude, at an elevation of 850 m). Soils at this site have formed on moderately fine-textured glacial till material. These soils, mapped as the Breton loam series, are classified as Orthic Gray Luvisols and Gleyed Gray Luvisols, and have formed under boreal forest vegetation (Lindsay *et al.* 1968).

The design of the crop rotation studies at both sites was previously presented in Chapter 2. Briefly, short-term crop rotations were initiated under two tillage systems at both sites, in order to compare the performance of these rotations with continuous cropping systems of barley and a perennial system of creeping red fescue (*Festuca rubra* L.). The crop rotation initiated in 1989 at both sites followed the sequence (1) barley, (2) barley-field pea (*Pisum sativum* L.) intercrop, (3) barley, (4) faba bean (*Vicia faba* L.). Rotations were established such that each phase of the rotation was represented by two replicates for each management system and year. The management systems for rotation crops at Ellerslie consisted of two tillage systems; no tillage (NT) and conventional tillage (CT). Under NT management, there was no mechanical soil disturbance except for the seeding operation, while the CT system consisted of two or three tillage operations per year using chisel ploughs, field cultivators, disks or harrows. At Breton, the two tillage practices were CT, and deep tillage (DT). The DT system consisted of an annual chisel operation to a depth of 0.3 m, in addition to the CT operations, as an attempt to penetrate the Bt horizon and increase the clay content of the Ap horizon.

3.2.2 Soil Sampling

Sampling for soil texture was performed at both sites prior to seeding in the spring of 1992. Six 15-mm diameter soil cores were obtained for the 0 to 0.15 m and 0.15 to 0.30 m soil depth intervals from each faba bean, barley- field pea intercrop and barley after faba bean cropping treatment of the rotation annual cropping system at each site.

Undisturbed core samples were used to determine soil water retention curves, pore size distribution and hydraulic conductivity and bulk density of tillage treatments within the rotation cropping system at each site. Sampling took place on August 10 and 11, 1992 approximately one week prior to harvesting crops at each site. One undisturbed sample, 76 mm in diameter and 76 mm in length, was taken from the inter-row region of each of the faba bean, barley-field pea intercrop and barley after faba bean cropping treatment plot, resulting in two replicates for each crop-tillage treatment at each site. Due to the dry soil conditions at this time, the sampled area was carefully wetted prior to extraction of the soil cores with a Uhland sampler. Moderate pressure was used to insert the sampler, and samples which exhibited cracking or compression were discarded. All samples were stored at 3 °C until the initiation of the laboratory analyses.

3.2.3 Laboratory Analyses

For textural analysis, a composite soil sample from each plot was air dried and ground to pass through a 2-mm sieve. Prior to analysis, organic matter was removed from the samples with repeated treatments of H_2O_2, using the method described by Gee and Bauder (1986). Particle size fractions (weight %) were determined using the hydrometer method for the sand, silt and clay fractions (Gee and Bauder 1986). For calculations, particle density was assumed to be 2.65 Mg m^{-3}.

Water retention characteristics and hydraulic conductivity of soil cores at soil water potentials from 3 kPa to 30 kPa were determined using the apparatus described in Fig. 3.1. The equipment allowed for the simultaneous analysis of five soil cores. Samples were saturated under vacuum with a de-aerated $CaSO_4$-thymol solution, using the procedure described by Klute and Dirksen (1986), prior to being placed in pressure-tight cells. Each cell assembly included one saturated soil core, a saturated high-conductance ceramic plate ($\approx$ 50 kPa pressure rating) at the base of the core, and a piece of 5.0 μm cellulosic paper placed between the soil and the ceramic plate to prevent contaminants from entering the plate.

For determination of Ks, de-aerated $CaSO_4$-thymol solution was flushed through each of the cells using a constant-head apparatus (Klute and Dirksen 1986). Outflow rate from the cells into 50 mL burets was monitored using pressure transducers (Foxboro model #1231 ±0.25 % accuracy rating) and a datalogger (Campbell Scientific model 21X). Darcy's Law was then used to calculate Ks:

$$Ks = \frac{J_w L}{(b + L)} \qquad (3.1)$$

where J_w water flux (m s^{-1}), b is the height of water applied (m) and L is the soil core length (m).

An outflow transient method (Gardner 1956; Klute 1972) was used to analyze hydraulic diffusivity and water retention characteristics for each sample. Constant air pressure, regulated by a water column, was applied to each sample. The resulting outflow rate of water from the cell was then measured using the pressure transducers and datalogger described above. Initially, an air pressure of 3 kPa was applied to the columns and allowed to equilibrate for 48 h while measuring the volume of solution released from the samples at 5 minute intervals. The pressure was then increased to 6 kPa and allowed to re-equilibrate. This process was repeated with increasing pressure at 3 kPa intervals until the total pressure applied to the samples was 30 kPa. Since the equilibration time required to reach the maximum outflow (Q_f) for each pressure is theoretically infinite, the data were fit to an exponential function proposed by Gardner (1956) using a non-linear least squares method.

$$Q(t) = (Q_f)(1 - 8/\pi^2)e^{(Dw)\left(\frac{\pi}{2L}\right)(ti)} \qquad (3.2)$$

In this way, parameter estimates for Q_f, the initial time t_i and hydraulic diffusivity D_W were obtained for each pressure increment.

The soil water retention curve values for pressures from 3 kPa to 30kPa were computed from the Q_f estimates, while water retention at 100 kPa and 1500 kPa were obtained from pressure plate data (Klute 1986). Subsamples of the soil cores analyzed by the outflow method were ground to pass a 2-mm sieve. Two samples were equilibrated at each pressure and the final water contents (mass basis) were calculated. Volumetric water content was determined by using the initial undisturbed core bulk density as a conversion factor.

. Soil pore size distribution for the pressure range from 0 to 1500 kPa was calculated from soil water retention data using the method outlined by Vomocil (1965). These calculations are based on the theory of capillarity in soils in which pore size distribution is related to the soil water characteristic curve (Childs 1940). Effective pore size can be calculated from soil suction using the equation:

$$h = \frac{2\sigma \cos\alpha}{\rho_W g r} \qquad (3.3)$$

where h is the soil suction, σ is the air-water surface tension, α is the contact angle between the soil surface and water, ρ_W is the density of water, g is acceleration due to gravity and r is the effective pore diameter (Jury *et al.* 1991). Using $\alpha = 0$, the diameter (in μm) of the smallest pore [equivalent pore diameter (EDP)] that will be drained at a given value of h (kPa) is approximately 300/h.

Values for unsaturated hydraulic conductivity [$K(\theta)$] were computed using the following relationship:

$$K(\theta) = \frac{d\theta}{d\psi} Dw \tag{3.4}$$

where $d\theta$ is the change in volumetric water content for each pressure increment, and $d\psi$ is the pressure increment applied. Determination of $K(\theta)$ by this method is subject to several assumptions. The main assumption in the use of the exponential equation (3.2) is that D_W is assumed constant over the time during which outflow takes place. Since D_W is known to change with water content, and water content is changing from t_i to t_f (the end of the equilibration period), the value for D_W calculated from the equation is a mean value. Error introduced by the estimation of D_W over a range of water contents can be reduced by using small pressure increments, which reduce the amount of change in water content (Gardner 1956). In this study, a relatively accurate method of measuring small amounts of outflow was established so that pressure increments would be held to 3 kPa. Other assumptions of this method which have been suggested as sources of error are: (i) the effect of gravity on outflow rate is negligible, and (ii) the flow impedance of the ceramic plate is minimal (Jackson *et al.* 1963; Klute 1972). Gravitational influence on water movement was assumed to be minimal since no outflow was observed until the application of air pressure to the cores. The influence of plate impedance was minimized by using ceramic plates with high conductance and limiting the analysis to a maximum of 30 kPa pressure.

Upon completion of the outflow analyses, the undisturbed soil cores were oven dried at 110° C for 72 h and weighed. Bulk density (ρ_b) was computed from the core volume and the oven dry weight for each sample.

3.2.5 Statistical Analyses

Water retention data as well as log transformed hydraulic conductivity vs. water content data for each site and tillage system were fitted to linear functions using least squares regression. The regression equations for sites and tillage systems were then compared to each other using a partial sum of squares technique. In this method, an F value is computed from the partial type I sum of squares for interaction terms and the full model mean square error to test the hypothesis that slopes and intercepts of the individual equations are the same (Ott 1993).

Direct comparisons between tillage systems for the parameters of clay content, bulk density, partitioned pore size fractions, and hydraulic conductivity with pressure ($K(\Psi)$) were conducted by analysis of variance using the General Linear Models (GLM) procedure in SAS (SAS Institute, 1985). Data sets were checked for normality using the W test (Shapiro and Wilk 1965) within the Univariate Procedure in SAS.

Results and Discussion

3.3.1 Soil Texture

Mean sand, silt and clay and organic carbon contents for soils at each site are given in Table 3.1. Comparison of each textural component between tillage systems at Breton revealed no significant differences in either sand, silt or clay in the upper 0.15 m of soil (Table 3.2; analysis not shown). Comparisons of texture between tillage systems at Ellerslie were not considered valid, since both NT and CT treatments had been tilled on a regular basis prior to 1986.

One of the aims of the DT treatment at Breton was to bring clay from the Bt horizon to the surface. If significant amounts of clay had been brought up near the surface, a textural difference between the tillage treatments should have been detected. Riddell *et al.* (1988) reported that clay was lifted from 0.4 m soil depth to 0.09 m soil depth by deep ripping on a Solonetzic soil in central Alberta, while Grevers and deJong (1990) reported that deep tillage implements loosen the soil with only very little inversion of material. The lack of difference between the treatments at Breton indicates that DT operations have not lifted significant amounts of clay to the surface horizon. The success of deep tillage depends to some extent on the equipment used and the frequency of the operation (Spoor 1986). In this case the effects were not observed even though annual DT operations were initiated in 1986 (Izaurralde *et al.* 1993).

3.3.2 Bulk Density

Mean bulk density values for sites and tillage systems are presented in Table 3.3. Bulk density differences between sites can be attributed to differences in sand, clay and organic carbon contents (Table 3.1). The effect of tillage systems on ρ_b at Ellerslie is consistent with the findings of other researchers in which an increase in this parameter has been observed under NT management (Bruce *et al.* 1990; Chang and Lindwall 1990; Hill 1990). No significant difference in ρ_b in the surface 76 mm of soil was observed between tillage systems at Breton. Effects of DT on ρ_b have been observed mainly in subsoil layers in other studies (Rowse and Stone 1981; Johnson *et al.* 1989), with no discernible effect on surface soil bulk density.

3.3.3 Soil Water Retention and Pore Size Distribution

Fitting outflow data from each pressure increment and soil sample to the exponential equation (3.2) resulted in correlation coefficients ranging from 0.85 to 0.99 with a mean R^2 for all treatments of 0.95. The fitted Q_f parameters from the outflow data as well as the pressure plate values calculated at 100 kPa and 1500 kPa were used to determine the relationship between soil water matric potential (Ψ) and water content (θ). This relationship is presented as a pF curve (where pF = $\log_{10}(-\Psi)$ in cm) for each site and tillage system. Although the soil water characteristic is thought to be a complex function for most soils (Childs 1940), the linear approximations to the characteristic curve (Fig. 3.2) had high coefficients of determination with R^2 ranging from 0.85 to 0.91 (Table 3.4). The calculated slopes and intercepts of pF curves provide convenient means of comparing the effects of tillage treatments on water holding characteristics. However, the physical significance of the Y intercept (the point where water content is theoretically zero) and of the X intercept (the point where θ = total porosity) cannot be determined from these functions, since the soil water characteristic likely deviates from the linear approximation as it approaches these limits (van Genuchten 1980).

Both the slopes and intercepts of the Breton and Ellerslie pF curves were significantly different. This difference can be attributed to several factors including differences in sand and clay contents, structural differences and a large difference in organic matter content of the two contrasting soils. Tillage systems differed at Ellerslie, where the slope of the pF curve for NT was steeper than that of the CT system, but the intercepts were the same. A steeper slope represents lower water holding capacity for small values of pF in the NT system. The similarity of intercepts between the two tillage systems at Ellerslie indicates that management affected water retention mainly when soil water content was high and values of Ψ were low. Water retention curves of the tillage systems at Breton did not differ significantly in either slope or intercept.

Pore size distributions for sites and tillage treatments are given in Fig. 3.3. The proportion of soil pores in the transmission size range (>50 μm) was similar for both sites, while the proportion of storage pores was greater in the 50 to 25 μm and 10 to 3 μm size ranges at Ellerslie. Samples from Breton had a greater proportion of pores in the small storage size range (3 to 0.2 μm), those from Ellerslie had a greater proportion in the residual (plant unavailable) size range of less than 0.2 μm. These differences in pore size distribution reflect differences in parent material and genetic history of the soils at the two sites. The greater proportion of larger storage pores at Ellerslie may be a reflection of the structural development of the Chernozemic A horizon, while the greater proportion of residual pores at this site is likely due to its higher clay content.

Tillage systems at Ellerslie had significant differences in pore size distribution in three size ranges. CT treatments had significantly greater proportions of small transmission and large storage pores than NT, while the NT treatments had a greater proportion of residual pores. These findings are consistent with those of Singh (1991) who found a greater proportion of pores in CT treatments in the 150 to 30 μm size range and a greater proportion of residual pores in NT treatments at a nearby site. Tillage appears to re-distribute pores from the residual size range to the transmission and large storage size ranges through mechanical disturbance (Greenland 1981). In this case a relatively short period of six years under NT has reversed these effects.

No differences were observed in pore-size distribution between tillage systems at Breton. In other studies the effects of deep tillage on porosity have been observed mainly in sub-surface soil layers (Rowse and Stone 1981; Johnson *et al.* 1989). The lack of observable differences between tillage treatments is likely due to the minimal effects of DT on the surface soil and variability in outflow data obtained from samples at this site.

3.3.4 Hydraulic Conductivity

Analysis of hydraulic conductivity data revealed great variability, particularly at values of Ψ near zero. Data were also found to be non-normal, and thus required transformation. Base ten logarithm (Log_{10}) transformation resulted in a normal distribution for these data. Transformed mean values (Log_{10} of $K(\Psi)$ in m s^{-1}) for Ellerslie and Breton differed significantly only in the 9 kPa pressure increment (Fig. 3.4). The transformed means of $K(\Psi)$ for tillage systems at Ellerslie were significantly different at 6 and 24 kPa of applied pressure. In both cases the NT samples exhibited a slower rate of water transmission than the CT samples. The lower value of $K(\Psi)$ at 6 kPa may be explained by the difference in pore size distribution between the treatments in the 100 to 50 μm and 50 to 25 μm EPD intervals. Since there are fewer total pores corresponding to 6 kPa pressure under NT, the conductivity associated with that pressure is lower. The difference between the tillage systems in $K(\Psi)$ at 24 kPa may not be as closely associated with pore size distribution. The EPD of $-\Psi = 24$ kPa is 12.5 μm, and the interval containing this size did not show any differences between tillage systems. The difference in $K(\Psi)$ at 24 kPa may reflect a difference in specifically sized pores (near 12.5 μm), or some improvement of storage pore continuity or connectivity under CT. Differences in saturated hydraulic conductivity between NT and CT treatments reported by Singh (1991) at Ellerslie were not observed in this study. Cropping system management, the length of time under NT, as well as sampling and analysis methodology differences between these two studies may account for the contradicting result. At Breton, saturated hydraulic conductivity of the DT system was greater than that of the CT system. Since no significant difference in large transmission-sized pores was observed between these systems, the greater Ks value observed is likely due to improved macropore continuity under the DT system.

As with pF curves, hydraulic conductivity functions K(θ) were estimated using a least squares linear approximation after K values were logarithmically transformed (Fig. 3.5, Table 3.5). Coefficients of determination for the functions ranged from 0.70 to 0.73. The slopes and intercepts of the K(θ) functions differed only between the two sites. The steeper slope at Breton indicated that conductivity decreased more rapidly with decreasing water content than at Ellerslie. Higher bulk density and lower clay content at Breton result in a lower total porosity for this soil compared to Ellerslie. Since fewer pores are available to transmit water at Breton, the conductivity will decrease more rapidly as water content is lowered. The lack of differences between slopes and intercepts of the K(θ) functions for tillage systems at both sites indicate that for a given water content the hydraulic conductivity of the soil will be similar, and that overall the soils of each site transmit water at the same rate, regardless of tillage system.

3.3.5 General Discussion

Bulk density, water retention and pore size distribution differed between Ellerslie and Breton. These differences may be attributed to differences in parent material (and the associated textural differences) and soil genesis. The effects of NT management on the surface soil at Ellerslie where observed in the form of increased ρ_b, reduced water retention at low matric potentials, altered pore size distribution, and lower unsaturated hydraulic conductivity at 9 and 24 kPa. These changes indicate that tillage increases the soil porosity and changes the pore size distribution, creating small transmission-sized and large storage-sized pores from residual pore space. The effect of this re-distribution is an increase in unsaturated hydraulic conductivity at matric potentials associated with small transmission-sized pores. There was no evidence of increases in Ks under NT as observed in other studies (Culley *et al.* 1987; Singh 1991). This parameter has been found to have great spatial and temporal variability, although it is also thought to be a sensitive indicator of management-induced changes (Jury *et al.* 1991). The hydraulic conductivity function was found to be similar under both tillage systems, indicating that other tillage-induced physical changes did not significantly alter the rate of water transmission at this site. Tillage management affected only the Ks of the surface soil at Breton. The increase in this parameter observed in the DT system may be an important factor in increasing drainage and reducing runoff potential in this soil. Deep tillage may also have effects on subsurface physical properties, but these were not studied in this experiment.

The effects which the tillage-induced changes in the soil physical environment may have on crop growth and water were not directly studied here. At both sites soil water storage, bulk density and hydraulic conductivity appear to be within acceptable limits for the growth of field crops [although "acceptable limits" of these physical parameters are not well defined (Singh 1991)]. The greater amount of surface soil water observed under NT at Ellerslie (Chapter 2) may be due to reduced surface evaporation or increased snow retention, since this tillage system exhibited a reduced water retention capability and similar hydraulic conductivity compared to CT. However, these possibilities are not explored in this study. A difference in soil water content between tillage systems at Breton was observed only in the surface soil of continuous barley treatments. Since these cropping treatments were not sampled as part of the laboratory work, the relationship of water storage and hydraulic conductivity of tillage systems between continuous cropping treatments and rotation treatments is unknown. The increased Ks observed with DT management within the rotation may also have occurred under continuous cropped barley, resulting in an increase in infiltration and possibly increased water content in the DT system.

3.4 Conclusions

The physical parameters of bulk density, soil water retention, pore size distribution and hydraulic conductivity of the surface 76 mm of soil differed between the Ellerslie and Breton site. These differences were associated mainly with soil type. The surface soils of the NT system at Ellerslie had a greater bulk density, lower water retention at small matric potentials, altered pore size distribution and similar hydraulic conductivity than those of the CT system. These findings did not help to explain the increased soil water observed in NT treatments over four years. The DT system at Breton had greater saturated hydraulic conductivity in the surface soil than the CT system.

Table 3.1 Mean soil texture and organic carbon content for two depth intervals at Ellerslie and Breton.

Site	Depth Interval	Sand	Silt	Clay	Organic C*
	m	dag kg^{-1}			
Ellerslie	0.0 - 0.15	17.4	43.3	39.3	5.0
	0.15 -0.3	17.9	43.9	38.2	5.0
Breton	0.0 - 0.15	32.0	42.9	25.1	1.4
	0.15 -0.3	32.3	34.7	33.1	0.4

*Organic carbon values from Izaurralde *et al.* (1993).

Table 3.2 Mean soil texture of the 0 - 0.15 m depth interval for tillage systems at Breton.

Tillage System*	Sand	Silt	Clay
	dag kg^{-1}		
Conventional Tillage	32.9	42.6	24.4
Deep Tillage	31.1	42.9	26.1

Table 3.3 Mean bulk density of undisturbed soil samples (0 to 76 mm soil depth) for sites and tillage systems.

Comparisons		Bulk Density	
		Mg m^{-3}	
Site			
	Ellerslie	0.91	a
	Breton	1.27	b
Ellerslie Tillage			
	CT	0.88	b
	NT	0.95	a
Breton Tillage			
	CT	1.24	a
	DT	1.29	a

Treatments within each comparison with the same letter are not significantly different at P=0.05.

Table 3.4 Comparisons of pF curves for sites and tillage systems using partial sum of squares.

Comparisons		Least Squares Equation	R^2	Slope	Intercept
Site					
	Ellerslie	pF = 5.37 - 8.42(θ)	0.87	*	*
	Breton	pF = 5.50 - 10.17(θ)	0.90		
Ellerslie Tillage					
	CT	pF = 5.19 - 7.88(θ)	0.89	*	NS
	NT	pF = 5.64 - 9.21(θ)	0.85		
Breton Tillage					
	CT	pF = 5.73 - 11.05(θ)	0.91	NS	NS
	DT	pF = 5.34 - 9.42(θ)	0.91		

* - Indicates significance of a partial F test comparing regression parameters at P = 0.05.

NS - not significant.

Table 3.5 Comparisons of curves of $-\text{Log}_{10}$ of hydraulic conductivity (m s^{-1}) versus θ (volumetric water content m^3 m^{-3}) for site and tillage treatments using partial sum of squares.

Comparisons		Least Squares Equation	R^2	Slope	Intercept
Site					
	Ellerslie	$\text{Log}(K) = 14.3 - 12.7(\theta)$	0.72	*	*
	Breton	$\text{Log}(K) = 14.7 - 15.7(\theta)$	0.73		
Ellerslie Tillage					
	CT	$\text{Log}(K) = 13.9 - 11.9(\theta)$	0.73	NS	NS
	NT	$\text{Log}(K) = 14.7 - 13.6(\theta)$	0.71		
Breton Tillage					
	CT	$\text{Log}(K) = 14.6 - 15.6(\theta)$	0.70	NS	NS
	DT	$\text{Log}(K) = 15.2 - 16.9(\theta)$	0.77		

* - Indicates significance of a partial F test comparing regression parameters at P=0.05. NS - not significant.

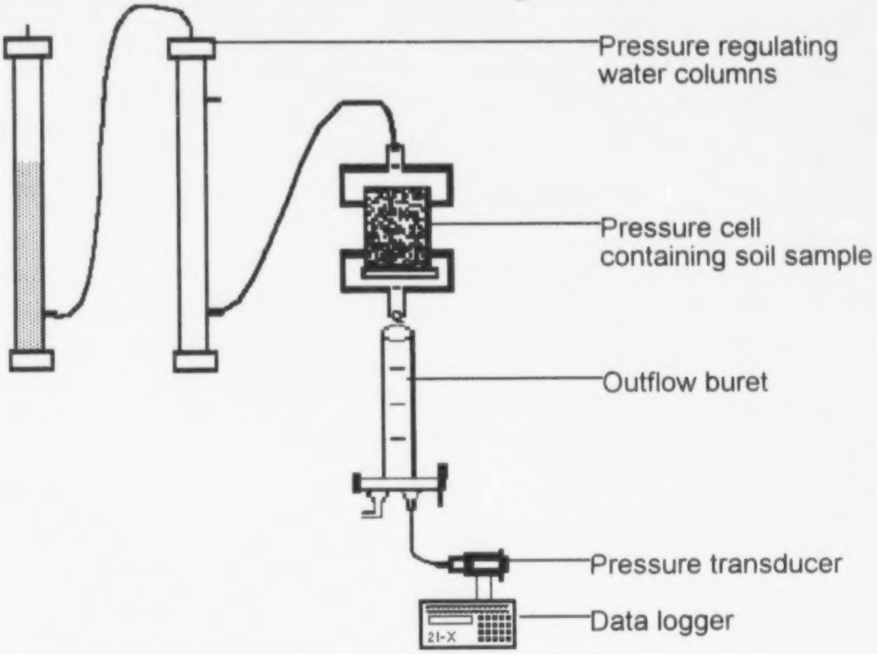
Pressure regulating water columns
Pressure cell containing soil sample
Outflow buret
Pressure transducer
Data logger
21-X

Figure 3.1. Schematic diagram of the apparatus used in transient outflow measurement of soil hydraulic parameters.

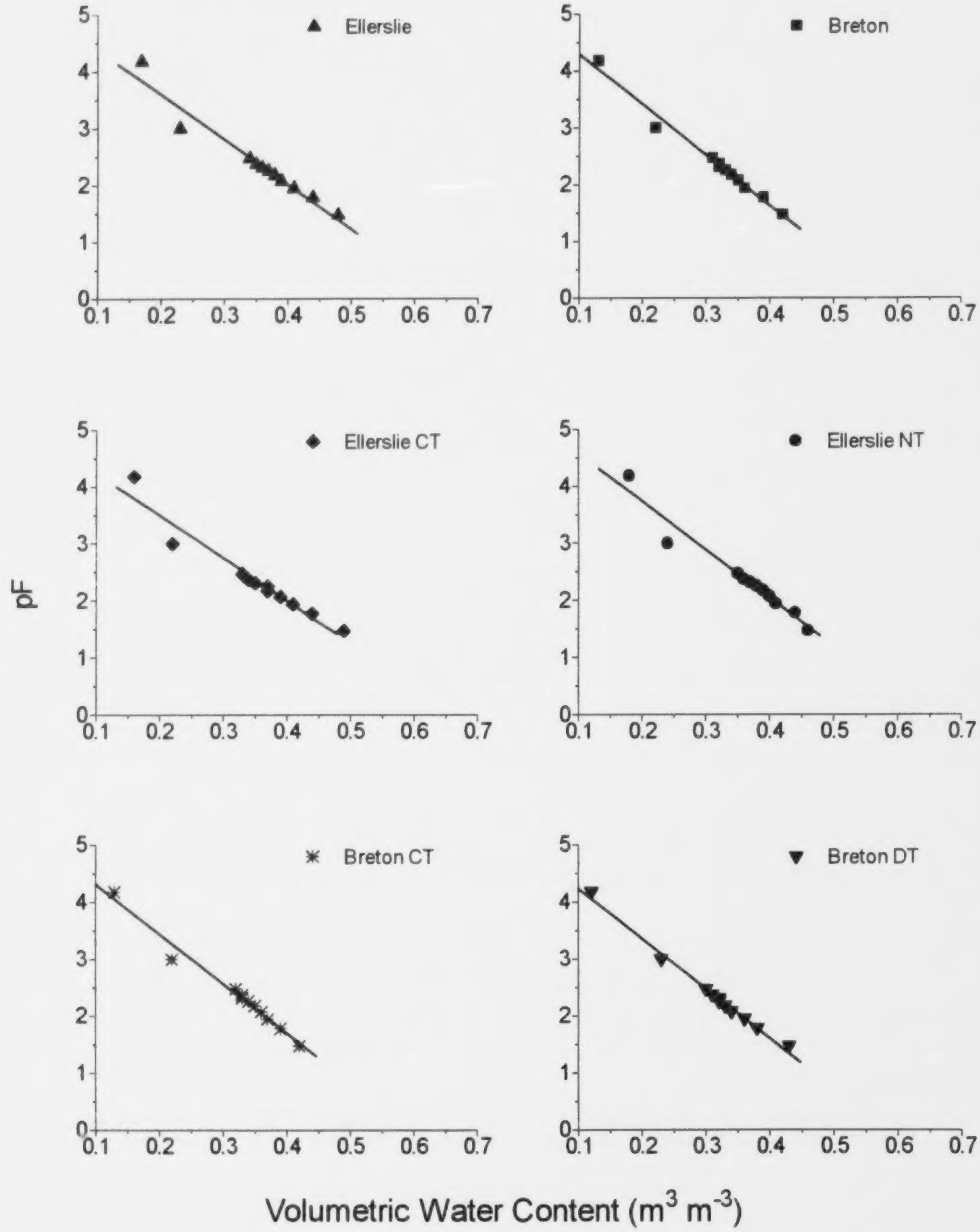

Figure 3.2 pF curves for Ellerslie, Breton and tillage systems at each site.

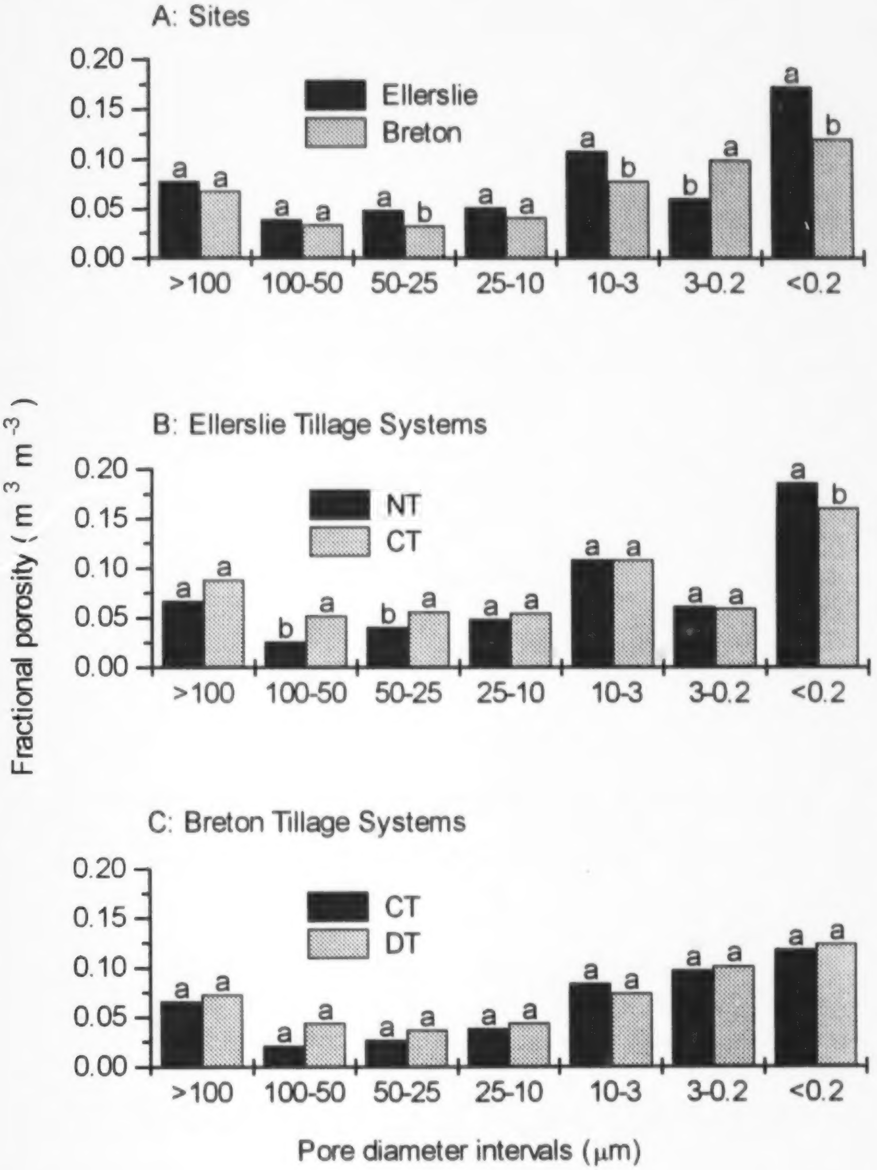

Figure 3.3. Pore size distribution (volume of pores in a given size interval as a fraction of total soil volume) for surface soils (0 to 76 mm) of (A) two sites, (B) tillage systems at Ellerslie and (C) tillage systems at Breton. Within each pore size interval, treatment means with the same letter are not significantly different (P=0.05).

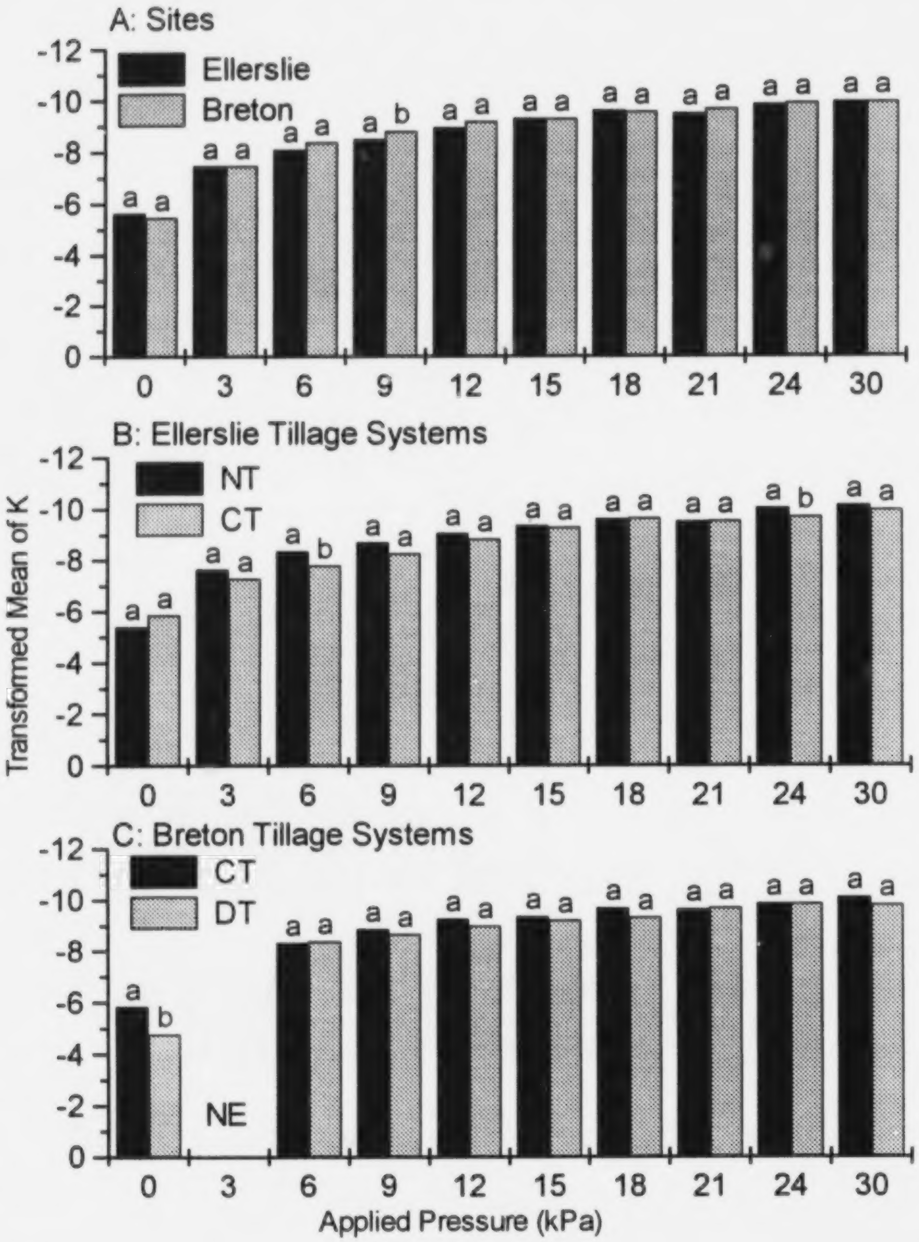

Figure 3.4. Transformed mean of hydraulic conductivity (Log_{10} K(Ψ)) for surface soils (0 to 76 mm) of (A) two sites, (B) tillage systems at Ellerslie and (C) tillage systems at Breton. Within each pressure increment, treatment means with the same letter are not significantly different (P=0.05).
NE - Not Estimated.

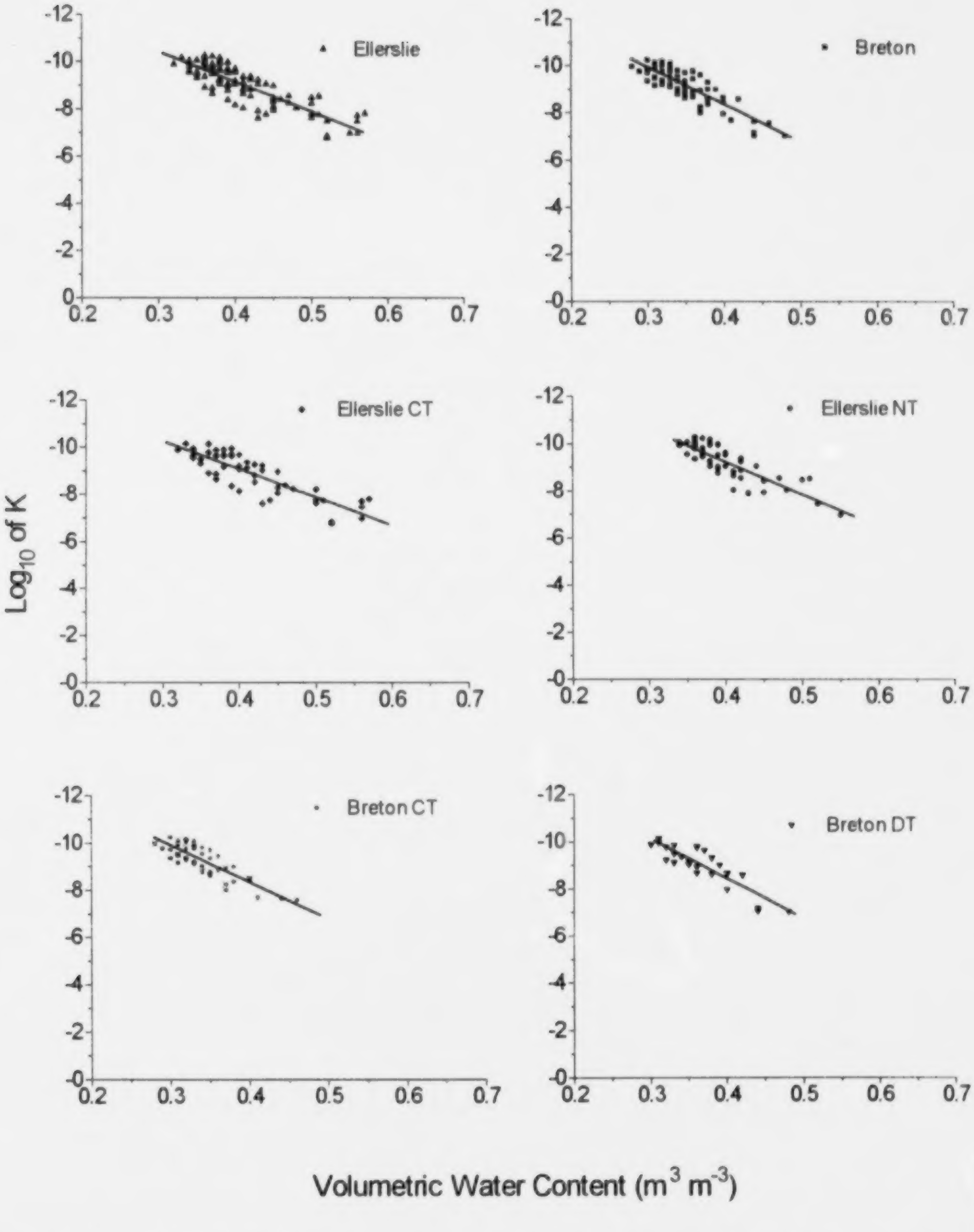

Figure 3.5 Log_{10} of hydraulic conductivity vs. water content for sites and tillage systems.

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Chapter 4

The effect of management on weed populations of alternative cropping systems in central Alberta.

4.1 Introduction

Efficient use of resources is one of the goals of sustainable agriculture. In the cropping systems of central Alberta, resources which limit production include water and nutrients. Although crop plants are the only species intentionally sown in this type of agroecosystem, undesired plants are almost always present. The presence of weed species in cropping systems leads to competition for limited resources between crops and weeds, and subsequently lower crop production. Management practices are often used to reduce or eliminate weed populations. These practices often rely on outside energy inputs into the cropping system, thus further increasing resource use. Weed-crop competition has been extensively studied. Reviews of this topic by Zimdahl (1980) and Berkowitz (1988) both concluded that species are usually in competition for light, water and nutrients and that the amount of each resource which each plant receives is a function of the relative populations and adaptive and management advantages which one plant species has over another.

A previous study (Chapter 2) reported greater surface soil water and water use efficiency of four year crop rotations under no-tillage (NT) with herbicide aided weed management than under a conventional tillage (CT) low input (LI) system using mechanical weed control. The effects of tillage on soil hydraulic properties were studied in Chapter 3. No direct link between tillage treatments and differences in soil water was revealed in the study. The objective of this study is to determine if the differences in management resulted in a difference in weed populations, and to discuss the effects which differing weed populations may have on the use of water resources in each management system.

4.2 Materials and Methods

Weed population sampling was conducted in 1991 and 1992 prior to seeding and harvesting in the final two years of a four-year rotation at Ellerslie in central Alberta. Details of the site and agronomic practices are given in Chapter 2. The crop rotation consisted of one year each of (1) barley (*Hordeum vulgare* L.), a (2) barley-field pea (*Pisum sativum* L.) intercrop, (3) barley and (4) faba bean (*Vicia faba* L.) under two management systems. Weed control under the LI system was accomplished by annual tillage operations, one in the fall after harvest and two in the spring prior to seeding. In the NT system herbicides were used for weed control. Each year the NT treatments received pre-emergent applications of glyphosate [N-(phosponomethyl) glycine] at a product rate of 2.5 L ha^{-1}. In 1991, barley treatments under NT received a post-emergent application of a mixture of Diclofop Methyl + Bromoxonil {methy 2-[4-(2,4-dichlorophenoxy) phenoxy] propionate and 3,5-dibromo-4-hydroxybenzonitrile} at product rate 3.5 L ha^{-1}. The herbicide used in 1992 was Thiefensulfuron methyl {methyl 3-[[[[[4-methoxy -6- methyl -1 ,3,5-triazin-2yl] amino] carbonyl] amino] sulfonyl]-2- thiophenecarboxylate} at product rate 20 g ha^{-1}. NT faba bean received post emergent applications of Bentazon [3-(1-methyl-ethyl)-(1H)-2,1,3-benzothiadiazin-4(3H)-one 2, 2-dioxide] at a product rate of 1.5 L ha^{-1}. NT barley-field pea plots received post emergent applications of MCPA + MCPB a 15:1 mixture of the sodium salts of MCPB [4-(2-methyl-4 chlorophenoxy) butyric acid] and MCPA. at a product rate of 1.5 L ha^{-1}.

The field experiment consisted of two replications for each phase of the crop rotation and each tillage system for a total of 16 plots. Weed population sampling was accomplished by counting the number of weeds of each species in three $1m^2$ quadrats on each plot. Counts were taken in 1991 on May 10 and August 26 and in 1992 on April 28 and August 20. Weed count data were analyzed for normality using the W test (Shapiro and Wilk, 1965) within the Univariate Procedure in SAS (SAS Institute 1987), and found to be inconsistent with normal distribution. Consequently, non-parametric analyses were performed on the data using the Kolmogorov-Smirnoff two-sample test. This test compares the empirical distribution functions of ranked samples within each management system and tests for differences between them (Daniel, 1978).

4.3 Results and Discussion

Both annual and perennial weeds were present in both years. Perennial species identified were: canada thistle (*Cirsium arvense* L.), dandelion (*Taraxacum officinale* Weber), perennial sow thistle (*Sonchus arvensis* L.) and quackgrass (*Agropyron repens* L.). Annual species were: chickweed (*Stellaria media* L.), cleavers (*Gallium aparine* L.), field bindweed (*Convolvulus arvensis* L.), field horsetail (*Equisetum arvense* L.), green foxtail (*Setaria viridis* L.), hemp-nettle (*Galeopsis tetrahit* L.), lamb's quarters (*Chenopodium album L.*), night-flowering catchfly (*Silene noctifloria* L.), shepherd's purse (*Capsella bursa-pastoris* L.), stinkweed (*Thlapsi arvense* L.), wild buckwheat (*Polygonum convolvulus* L.), wild mustard (*Sinapis arvensis* L.) and wild oats (*Avena fatua* L.). In addition, volunteer barley was counted in faba bean treatments. Analysis of the populations of individual weed species at this site is presented by Izaurralde *et al.* (1993). They reported that hemp-nettle was the single most important annual weed species encountered on these plots, and that barley-field pea intercrop plots were least affected by this weed. They also found that perennial weed species were fewer in number than annual species.

The distribution of total weed count data differed between management systems on all sampling dates (Table 4.1). Total weed distributions between management systems within crop types (barley crops and crops including legumes) were also different in all cases. Populations were also compared by weed type (annual or perennial). Annual weed populations between management systems of the full rotation and for barley crops had different distributions in three of the four sampling dates, while legume crops differed only in the pre-harvest samples in 1991 and 1992. Perennial weed populations differed between management systems in the full rotation only in the pre-harvest sample in 1991, while these comparisons within legume crops differed in the fall of 1991 and the spring of 1992. Perennial weed distributions between NT and LI in barley crops did not differ in any sample.

The Kolmogorov-Smirnoff test described above tests for differences in distribution with respect to location and dispersion (Daniel 1978). A greater number of counts in one treatment compared to another would lead to differences in distribution due to location. In the case of the analyses presented here, the total number of weeds counted under the LI system were consistently greater than in the NT system, resulting in observed differences in distribution. However, differences in the annual weed populations between management systems in the August 1992 sampling date are likely due to differences in dispersion of the distributions. In this case barley crops had greater weed populations under LI than NT, while legume crops displayed the opposite trend.

The implication of significantly greater numbers of weeds in the LI system is that competition for limited resources within the LI system will be greater than under NT. If light, water and nutrients were available in similar quantities in both management systems, the expected result of increased weed competition under LI would be reduced resource use efficiency per unit dry matter of crop produced. In Chapter 2, crop rotations under these two management systems were found to have similar amounts of seasonal evapotranspiration over four years, but different water-use efficiencies. This difference in efficiency may be attributable to differences in weed-crop competition associated with greater weed populations under LI. In this case smaller weed populations would not account for the greater amount of soil water found under NT management, since evapotranspiration is constant across both systems. The difference in soil water between the systems could be due to other factors not studied here, such as reduced surface evaporation or increased snow retention caused by differences in residue cover.

Table 4.1 Comparisons of weed counts between tillage systems within the rotation cropping system at Ellerslie using the Kolmogorov-Smirnoff two sample test.

Date	Comparison		Total weeds†	Ksa ††	Annual weeds	Ksa	Perennial weeds	Ksa
May 10 1991	Rotation	NT	483	4.915 *	472	0.814 NS	11	0.749 NS
		CT	777		538		239	
	BA in Rotation	NT	238	3.167 *	233	0.599 NS	5	0.770 NS
		CT	447		324		123	
	FA and IN in rotation	NT	245	3.877 *	239	0.517 NS	6	0.762 NS
		CT	330		214		116	
Aug 26 1991	Rotation	NT	557	6.636 *	497	7.167 *	80	2.025 *
		CT	984		846		138	
	BA in Rotation	NT	233	3.105 *	190	3.445 *	43	1.354 NS
		CT	381		310		71	
	FA and IN in rotation	NT	344	6.092 *	307	6.488 *	37	1.810 *
		CT	503		536		67	
Apr 28 1992	Rotation	NT	435	2.705 *	415	2.447 *	20	0.584 NS
		CT	555		436		119	
	BA in Rotation	NT	196	4.731 *	180	4.817 *	16	0.701 NS
		CT	306		262		44	
	FA and IN in rotation	NT	239	3.141 *	235	0.649 NS	4	1.819 *
		CT	249		174		75	
Aug 20 1992	Rotation	NT	538	3.641 *	504	5.213 *	34	1.064 NS
		CT	652		501		151	
	BA in Rotation	NT	238	6.032 *	206	7.292 *	32	1.084 NS
		CT	323		253		70	
	FA and IN in rotation	NT	300	3.305 *	298	4.223 *	2	0.655 NS
		CT	329		248		81	

NT - No Tillage, CT - Conventional Tillage, BA - barley, FA - Faba bean, IN - Barley-field pea intercrop

† - Total number counted.

†† - Ksa = Kolmogorov asymptotic test statistic. * - Indicates the significance of the Kolmogorov-Smirnov test at the 0.05 level of probability.

NS = Not significant.

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Chapter 5
Synthesis

5.1 Introduction

Alternative cropping systems have the potential to reduce or reverse the effects of soil degradation often associated with conventional production methods in central Alberta. Further benefits of alternative systems include reduced reliance on non-renewable resources and potential economic diversity for producers. The extent to which these potential benefits can be realized depends on the suitability of the crops, cropping sequences and management techniques to the region. One criterion on which this suitability depends is the use of water. The studies presented here attempt to take an integrated approach to determining the water use patterns of cropping systems relative to one another.

5.2 Cropping System Effects on Soil Water Dynamics

The four year study (1989 to 1992) compared the soil water dynamics of conventional and alternative cropping systems at two sites, with contrasting soil types and differing local climatic patterns, over four years. The seasonal amounts of soil water were strongly correlated with precipitation at both sites, indicating that annual variability of soil water was mainly influenced by climatic factors. Levels of soil water also differed between crops and cropping systems over the four year study period. At Breton total soil water from 0.05 to 0.8 m followed the pattern continuous barley > rotation annual crops > continuous forage (creeping red fescue). At Ellerslie, profile soil water was similar in all treatments. Despite differences in soil water observed at Breton, ET was similar between both annual cropping systems at each site. Explanations for this result are either that greater amounts of soil water in the continuous cropping system at Breton were spatially or temporally unavailable for plant growth, or that plants were unable to use the excess soil water in this system because other resources, such as soil nutrients, were limiting crop production.

At Ellerslie on a Black Chernozem, soil water was considered to be limiting to crop production over four years, while at Breton on a Gray Luvisol availability of soil water did not limit the overall production of the cropping systems. Compared to Ellerslie, the Breton site had greater amounts of growing season precipitation, resulting in greater amounts of soil water. Analysis of factors affecting the variability of WUE showed that at Breton, nitrogen may limit growth more than water does, since crops which were able to fix nitrogen or had N fertilizer added had greater water-use efficiencies than unfertilized crops.

5.3 Management Effects on Soil Water Dynamics

Management factors within each cropping system were found to affect soil water status, ET and WUE. At Breton the influence of the two tillage systems, CT and DT on soil water occurred within the continuous annual cropping system. In Chapter 3 disturbed and undisturbed soil samples from each tillage system within the rotation cropping system at this site were analyzed for differences in texture, bulk density and water-related physical properties to determine if these differences were related to tillage. No changes in texture or bulk density between tillage systems were found, but there was a modest increase in saturated hydraulic conductivity between tillage systems. Since analysis of the physical properties was only performed on one cropping system, and differences in soil water were observed only in the unsampled cropping system, the results were unable to support the observations made in

Chapter 2. Water use efficiency was affected by tillage system only within the faba bean cropping treatment at Breton. Here faba bean grown under DT had greater WUE than those under CT. This result occurred even though ET was similar in both tillage systems. Rengasamy and Reid (1993) had similar findings, but were unable to explain the reasons for the difference in WUE. They suggested that faba bean responded to the altered soil profile in ways not related to plant transpiration.

Effects of management variables on soil water parameters at Ellerslie were observed only within the rotation cropping system. Greater amounts of soil water were observed under NT management within this cropping system over four years. This has been a common observation in tillage studies (Singh 1991) and has been attributed to reductions in surface runoff and surface evaporation (Blevins, *et al*. 1971; Dick *et al*. 1989, Arshad and Dobb 1991). Analysis of the surface soils under NT and CT within the rotation system revealed a difference in bulk density and a shift in pore size distribution but no large difference in saturated or unsaturated hydraulic conductivity between the two tillage systems. It was concluded that on the basis of surface soil physical properties the amount of soil water between the two systems should be similar. The effects of residue management, which was a part of the management systems, but not studied here may account for the difference in soil water between the two systems. No significant differences in ET between the management systems were observed within this rotation, however there were significant differences in WUE between them. Since the management systems within the rotation differed not only in tillage and residue management but also in weed control methods, a study was initiated to determine if differences in weed populations might account for the difference in WUE. Weed populations were found to be greater under the CT-low input system within the rotation than in the NT system. Increased crop-weed competition within the LI system at Ellerslie may explain the significant difference in WUE between the two management systems.

5.4 Conclusions

Specific conclusions reached from these studies are:

(1) At Breton, the amount of soil water from 0.05 to 0.3 m differed with cropping system in the order continuous annual crop > rotation annual crops > continuous forage crop, while at Ellerslie cropping system did not affect total soil water.

(2) ET was similar between annual cropping systems at both sites over a four year period.

(3) WUE was affected by annual cropping system at Ellerslie, but not at Breton.

(4) Soil water was a limiting factor for plant growth at Ellerslie, but not at Breton.

(5) Tillage system within the rotation cropping system affected surface soil bulk density and pore size distribution at Ellerslie.

(6) Tillage system within the rotation cropping system affected the saturated hydraulic conductivity of surface soils at Breton.

(7) Weed populations were greater under LI management than under NT management within the rotation cropping system at Ellerslie.

From a standpoint of soil water use, the alternative cropping system proposed in these studies appears to be similar to that of the conventional system. Short-term crop rotations which include annual legumes must be carefully considered in areas where soil water deficits are common, such as at Ellerslie. Here, crops with greater rates of ET, such as faba bean may have lower productivity (WUE) than conventional cereal crops, but do not appear to deplete soil water for the following crop.

5.5 Possibilities for Future Research

While short-term crop rotations such as the one in these studies show promise in reaching the goals of sustainability, considerable "fine tuning" particularly with respect to site-specific management practices must be undertaken. Future research efforts in this field should include:

(1) More intensive study of hydrologic parameters particularly with respect to the contributions of snow, surface evaporation, runoff, and subsurface drainage. Ideally transpiration and evaporation should be determined separately in order to gain a better understanding of management effects on crop water use.

(2) Study of individual plant water resource use within a competing environment. The effects of weed population dynamics and the individual effects of barley and field pea within an intercrop on water use have been greatly simplified in this study. Further work, perhaps by determining leaf water potentials would provide details in this regard.

(3) Study of the effects of deep tillage on root distribution, particularly of faba bean. Some work has been done on this topic, but so far no reasonable explanation for increased WUE of faba bean under this tillage system has been provided.

(4) Study of the effects of residue management within alternative cropping systems on hydrologic parameters. The effects of different amounts and types of residue from

rotation crops on the water status of succeeding crops has not been studied at these sites.

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